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GREENHOUSE EFFECT ON GROWTH AND YIELD OF TOMATO IN THE TRANSITIONAL ZONE OF GHANA

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BY

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A DISSERTATION IN THE DEPARTMENT OF CROP AND SOIL SCIENCES EDUCATION, FACULTY OF AGRICULTURE EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES UNIVERSITY OF EDUCATION, WINNEBA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF EDUCATION IN AGRICULTURE (CROP SCIENCE)

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DECLARATION

I, Amoah, Patience Oye, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and acknowledged, is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

SIGNATURE:………………………………….

DATE:…………………………………………

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

Mr. E.K Asiedu (Principal Supervisor)

Signature:…………………………………

Date:……………………………………....

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DEDICATION

This work is dedicated to my mother, Madam Mary Amoah and my son, Nana Yaw Ofosuhene Abankwah. I am so grateful for their love, prayer and support till the end of the programme.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Tomato is one of the most popular vegetables consumed in Ghana. With the increasing demand for tomato on daily basis, there is the need to increase productivity. However, the production of tomato in Ghana is limited by harsh climate, drought and inadequate knowledge on the use of modern technology such as greenhouse technology. Hence, the purpose of the study was to investigate the effect of greenhouse technology on the growth and yield of tomato in the transitional zone of Ghana. The experiment was conducted at the multipurpose Crop Nursery of the former University of Education, Winneba (now AAMUSTED) College of Agriculture Education Mampong Campus from 4th August, 2020 to 30th November, 2020. The experimental design used for the study was Random Complete Block Design. Two treatments made up of greenhouse technology and open field were used. Parameters measured included: plant height, number of branches, stem girth, number of flowers, number of fruits harvested, harvested fruit weight, matured vertical fruit length and diameter and economic analysis. The data collected were analysed using the Student T-test using Genstast version 11.1. Results from the study revealed that plant height, number of branches and stem girth were significantly higher ($P<0.05$) among tomato plants grown in the open field compared with tomato plants grown under the greenhouse technology. Number of harvested fruits, harvested fruit weight, matured vertical fruit length and diameter were significantly ($P<0.05$) highest among tomato plants grown under the greenhouse technology as compared with tomato plants grown in the open field. This study concludes that greenhouse technology increased the yield of tomato with higher economic returns. The study recommends that farmers should adopt greenhouse technology, since it gave higher productivity and economic returns.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

The tomato *(Lycopersicon esculentum*), belongs to a family known as Solanaceae, and is commercially important throughout the world both for the fresh fruit market and the processing industries (Costa & Heuvelink, 2018). It is grown in a wide range of climates in the field, under protection in plastic greenhouses and in heated glasshouses (Gruda *et al.*, 2019). World-wide, it is the most important vegetable. In Northern Europe, the tomato is one of the major greenhouse crops (Soto *et al.*, 2014).

Although cultivated as an annual, tomato grows as a struggling perennial in its original habitat in the Western coastal plain of Northern South America (Estabrook, 2012). Tomato, is consumed in different ways, including raw, as an ingredient in many dishes and sauces and in drinks (Perveen *et al.*, 2015).

The fruit of tomato, classified as a vegetable in trade, is a prominent "protective food" (Waheed *et al.*, 2020). In areas where it is eaten, it forms a very important part of human food (Sinha & Khare, 2017). Tomato, for example, forms a very important component of food consumed in Ghana and this is evident in the fact that many Ghanaian dishes have tomatoes as a component ingredient (Addo *et al.,* 2015).

Tomato is a rich source of folate and with phytonutrients, the most abundant in tomatoes are the carotenoids, lycopene being the most prominent, followed by beta-carotene and gamma-carotene, phytoene as well as several minor carotenoids (Aggarwal *et al*., 2016). In spite of the modest levels of beta-carotene and gamma-carotene in tomato products, due to their pro-vitamin A activity, a high consumption of the vegetable and its products result in a rich supply of vitamin A in the body. Lycopene, an antioxidant, purportedly fights the free radicals that can interfere with normal cell growth and activity (Boateng *et al.*, 2017). These free radicals according to Poprac *et al*. (2017), can potentially lead to cancer, heart disease and premature old age.

These nutritional facts are good reasons to support the tomato industry of Ghana as far as the production, storage, processing, distribution and consumption are concerned.

1.2 Problem Statement

According to Robinson and Kolavalli (2010), the agricultural sector in general and the tomato sector in particular have not met their potential in Ghana to meet the increasing population demand for tomatoes due to low crop yield compared with potential yield resulting in an increase demand for the crop (tomato) supply far below demand (Ntinas *et al.*, 2017).

Also, due to the importation of tomatoes and its products into the country to complement the production in Ghana, huge amount of money is used for heavy importation of crop in various forms leading to loss of foreign exchange (Guodaar, 2015). Again, there is heavy post-harvest losses as a result of pests and diseases infestation, inadequate processing and storage facilities among other (Chakraborty *et al.*, 2018).

More so, the various farming systems should be explored in order to select the one that will suit tomato production in order to increase crop yield per unit area, produce quality fruits with improved post-harvest shelf life and reduce post-harvest crop spoilage.

1.3 Main objective

The purpose of the study is to determine the effect of greenhouse and open field environment on the growth, yield and post-harvest shelf life after harvesting of tomato fruits (*Lycopersicon esculentum*).

1.4 Specific objectives

Specific objectives of the study are:

1. To investigate the sole effect of greenhouse and open field environments on the growth of tomato.
2. To compare the effect of greenhouse and open-field environments on the yield of tomato.

1.5 Significance of the Study

This study will bring to bear important information on the effect of greenhouse and open field environments to improve growth condition and increase yield of tomato. The findings of this study will also encourage farmers to select the appropriate environment to maximize growth and yield of tomato production. Recommendations from this study will help increase yield and fruit quality of the crop, improve household income and food security. It will also lead to reduction in rural-urban migration. When tomato is in abundance in the country it helps in conservation of foreign exchange through reduction of its importation. It again leads to increased consumption of tomato to help improve health and nutrition of farmers.

1.6 Limitations

The main limitation of this project has something to do with timing and equipment. Equipment required to be used in the Greenhouse are very expensive. For instance, the drip-lines, polytanks, chemicals, thermometers, ventilators are readily inadequate and costly. Also, operating in the Greenhouse is time demanding and needs a committed person to be successful there.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution

Tomato belongs to the *Solanaceae* family. This family also includes other well-known species, such as potato, tobacco, peppers and eggplant (aubergine) (Gebhardt, 2016). The natural geographic distribution or centre of origin of *Solanum lycopersicum*, (*S.* section *Lycopersicon*) has been localized in the narrow land between the Andes Mountain ranges and the Pacific coast of western South America. This extends from southern Ecuador to northern Chile, including the Galapagos Islands (Grandillo *et al.*, 2011; Ozturk *et al.*, 2019). This is based on the geographic distribution of the native wild ancestors of the genus between coordinates 0 º - 20 º S and 64 º -81º W where they grow spontaneously and sympatrically (Blanca *et al.*, 2012).

Based on research from the Tomato Genome Consortium 2012, the three wild species most closely related to cultivated tomato include the red-fruited species *S. pimpinellifolium* and the orange-fruited species found on the Galapagos Islands, *S. galapagense* and *S. cheesmaniae* (Strickler *et al.*, 2015).

Mexico is presumed to be the most probable region of domestication, with Peru as the center of diversity for wild relatives (Porch *et al.*, 2013). According to Sowley and Damba (2013), tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetables worldwide. World tomato production in 2001 was about 105 million tons of fresh fruit from an estimated 3.9 million ha. As it is a relatively short duration crop and gives a high yield, it is economically attractive and the area under cultivation keeps increasing daily (Adepoju, 2014).

Tomato has its origin in the South American Andes. The cultivated tomato was brought to Europe by the Spanish conquistadors in the sixteenth century and later introduced from Europe to southern and eastern Asia, Africa and the Middle East. More recently, wild tomato has been distributed into other parts of South America and Mexico (Bergougnoux, 2014). Common names for the tomato are: tomate (Spain, France), tomat (Indonesia), faan ke'e (China), tomati (West Africa), tomat (Nahuatl), jitomate (Mexico), pomodoro (Italy), nyanya (Swahili) (Masunga, 2014).

The cultivated tomato, *Solanum lycopersicum* L., is the world's most highly consumed vegetable due to its status as a basic ingredient in a large variety of raw, cooked or processed foods (Bhowmik *et al.*, 2012). Tomato is grown worldwide for local use or as an export crop. In 2014, the global area cultivated with tomato was 5 million hectares with a production of 171 million tonnes, the major tomato-producing countries being the People's Republic of China (hereafter "China") and India (Bhowmik *et al.*, 2012). According to Welbaum (2015), tomato can be grown in a variety of geographical zones in open fields or greenhouses, and the fruit can be harvested by manual or mechanical means. Under certain conditions (e.g. rejuvenation pruning, weeding, irrigation, frost protection), this crop plant can be perennial or semi-perennial, but commercially it is considered an annual.

Although there are many types of growing systems for greenhouse tomatoes, the two principal cropping systems are two crops per year and one crop per year. Its importance lies not only in profit, but also in the income generated in local economies for farmers and agricultural workers (Manandhar *et al.*, 2011).

Protected agriculture is a wide category of production method providing some degree of control over various environmental factors. This category includes production technologies such as: greenhouses, glasshouses, tunnels and covered fields (Castilla, 2013). Although there is no quantitative data about the world's vegetable production in greenhouses, some calculations have been made (Anderson *et al.*, 2016). For example, in 2012, the greenhouse vegetable production was about 81 million kilograms (kg), of which 40 million kg was tomato, and 37 million kg was cucumber. More specifically, in 2012, the tomato production in greenhouses in North America accounted for 52% of the market in Canada and the 22% of the market in the United States (Nordey *et al.*, 2017).

Cultivated tomato is related to wild tomatoes originating from Peru, Ecuador and other parts of South America including the Galapagos Islands. The centre of its domestication and diversification is Mexico (Blanca *et al.*, 2015). Wild relatives of tomato and intermediate forms (landraces or creoles) harbour a wealth of genetic diversity and are important sources of genetic material in crop improvement and conservation programmes (van Zonneveld *et al.*, 2019; van Zonneveld *et al.*, 2020).

Tomato is a perennial herbaceous plant but it is often grown as an annual crop even if biennial and perennial forms exist. Tomato is cultivated in tropical and temperate climates in open field or under greenhouse in temperate climate. Greenhouses are often used for small-scale production. In warm climate with the right light intensity for growth, around 45 days are necessary from germination to vegetative growth and 90-100 days to reach the beginning of fruit ripeness (Dixon *et al.*, 2014). The end use of the crop, whether for the processing market or fresh market, will determine the cultivars sown, the time of harvest and harvest processes, which can be manual or mechanical (Zhang *et al.*, 2016).

2.2 Botanical description of tomato plant

Tomato plant has vigorous tap root system that grows to a depth of 50 cm or more. The main root produces dense lateral and adventitious roots (Fageria and Moreira, 2011). Growth habit of the stem ranges between erect and prostrate. It grows to a height of 2-4 m. The stem is solid, coarse, hairy and glandular (Abraham and Thomas, 2017).

The leaf is spirally arranged, 15-50 cm long and 10-30 cm wide. Leaflets are ovate to oblong, covered with glandular hairs. Small pinnates appear between larger leaflets (Xu and Deng, 2017). Inflorescence is clustered and produces 6-12 flowers. Petiole is 3-6 cm. The flower is bisexual, regular and 1.5-2 cm in diameter. They grow opposite or between leaves. Calyx tube is short and hairy, sepals are persistent. Usually 6 petals up to 1 cm in length, yellow and reflexed when mature. 6 stamens, anthers are bright yellow in colour surrounding the style with an elongated sterile tip. Ovary is superior and with 2-9 compartments. Mostly self- but partly also cross-pollinated. Bees and bumblebees are the most important pollinators (Manning, 2018).

The fruit is fleshy berry, globular to oblate in shape and 2-15 cm in diameter. The immature fruit is green and hairy. Ripe fruits range from yellow, orange to red. It is usually round, smooth or furrowed (Amaefula, 2017). Seeds are numerous, kidney or pear shaped. They are hairy, light brown 3-5 mm long and 2-4 mm wide. The embryo is coiled up in the endosperm. Approximate weights of 1000 seeds are 2.5 – 3.5 g (Salim, 2017).

The growth habit of the plant varies from indeterminate to determinate and may reach up to 3 metres (m) in height (Zahedi and Ansari, 2012). The primary root may grow several metres in length. The stem is angular and covered by hairy and glandular trichrome that confer a characteristic smell. Leaves are alternately arranged on the stem with a 137.5° phyllotaxy. Leaves range in shape from lobed to compound, with segments arranged pinnately. Compound leaves are typically comprised of five to nine leaflets. Leaflets are petiolated and dentated. All leaves are covered by glandular, hairy trichomes (Keller, 2020).

The tomato fruit is globular or ovoid. Botanically, the fruit exhibits all of the common characteristics of berries; a simple fleshy fruit that encloses its seed in the pulp. The outer skin is a thin and fleshy tissue that comprises the remainder of the fruit wall as well as the placenta. The colour of the fruit is derived from the cells within the fleshy tissue (Hari, 2019).

Tomato fruits can be either binocular or multinodular. Between 50 and 200 seeds are located inside the locular cavities and are enclosed in gelatinous membranes. On average, the seeds are small (5 x 4 x 2 mm) and lentil shaped. The seed contains the embryo and the endosperm and is covered by a strong seed coat, called the testa. The development of the fruit takes seven to nine weeks after fertilization. The many end uses of tomato fruit, as well as food and feed safety considerations, including composition of key food and feed nutrients, anti-nutrients, allergens, and toxicants, are detailed in the "OECD consensus document on compositional considerations for new varieties of tomato" (Khare and Bhale, 2016).

Yellow tomatoes have higher vitamin A content than red tomatoes, but red tomotoes contain lycopene, an anti-oxidant that may contribute to protection against carcinogenic substances (Chaudhary *et al.*, 2018).

Tomato is an annual plant, which can reach a height of over two meters. In South America, however, the same plants can be harvested for several years in succession. The first harvest is possible between 45-55 days after flowering, or 90-120 days after sowing. The shape of the fruit differs per cultivar. The colour ranges from yellow to red (Deribe *et al.*, 2016).

The tall and bush types are entirely different kinds of crops. The tall varieties are the best choice for a long harvest period. They keep growing after flowering. This feature is called indeterminate. However, under tropical conditions, diseases and insect attacks will stop growth of the tomato plant. The plants generally have more foliage. This will keep the temperature lower within the crop and the fruits grow in the shade of the leaves (Bita and

Gerats, 2013). Because they are covered, the sun does not damage the fruits and they ripen more slowly. Slower ripening and a high leaf/fruit ratio improve the taste of the fruits and in particular the sweetness. The tall types have to be staked, caged or trellised (Abdussamee *et al.*, 2014).

According to Abdussamee *et al.* (2014), short types usually support themselves and need no staking. Under severe weather conditions such as typhoons, however, staking may be advisable. Determinate types stop growing after flowering. They require less labor, so they are popular for commercial cultivation. They have a relatively concentrated fruit set which lasts only two or three weeks and the fruits ripen much faster than those from indeterminate types (Estabrook, 2012).

2.3 General Taxonomy

The cultivated tomato is a member of the genus *Solanum* within the family Solanaceae. The Solanaceae, commonly known as the nightshade family, also includes other notable cultivated plants such as tobacco, chilli pepper, potato and eggplant (Shah *et al.*, 2013).

Tomato classification has been the subject of much discussion and the diversity of the genus has led to reassessment of earlier taxonomic treatments. Tomato was originally named *Solanum lycopersicum* by Linnaeus in 1753; *lycopersicum* (L.) Karsten has also been used (Alelign, 2020). Knapp and Peralta (2016) in *The Gardener's Dictionary* used *Lycopersicon esculentum*. Lebeda *et al*. (2014) included nine species in the *Lycopersicon* genus. For a long time, tomatoes were known as *L. esculentum*, but recent research has shown that they are part of the genus *Solanum* and are now again broadly referred to as *Solanum lycopersicum* (Seid *et al.*, 2015).

The genus *Solanum* consists of approximately 1,500 species. The tomato clade (section *Lycopersicon*, formerly recognised as the genus *Lycopersicon*) includes the cultivated tomato (*Solanum lycopersicum*) and 12 wild relatives, all natives to western South America (Grandillo *et al.*, 2011). Tomato (*Solanum lycopersicum*) is derived from two wild ancestral species, *Solanum pimpinellifolium* and *Solanum cerasiforme*. Other wild species are useful for breeding disease resistance, colour improvement and desirable quality traits (Strickler *et al.*, 2015).

The 12 wild members of the *Lycopersicum* clade demonstrate a high level of phenotypic and genetic variation, including a great diversity in mating systems and reproductive biology (Jewell *et al.*, 2020). Parrella (2020) recognized 12 species of wild tomato; this was an increase on the 9 species of tomato recognized. Within these 12 species, informal species groupings were made: 4 closely related green-fruited species – *S. arcanum*, *S. huaylasense*, *S. peruvianum* and *S. corneliomulleri* – were grouped in the *S. peruvianum sensu lato* (*sensu lato* refers to a broad concept of species). Another group of yellow to orange-fruited species contains two species endemics to the Galapagos Islands: *S. galapagense* and *S. cheesmaniae* (Knapp and Peralta, 2016).

2.4 Crop Migration

Historical records allow the reconstruction of the arrival of tomatoes in the Old World, following European contact. The Spanish navigators brought seeds to Europe in the 16th century and friars sent some of these to their brothers (Kupperman, 2012).

The tomato first arrived in Andalusia (via the Canary Islands) and was dispersed throughout Spain. The Spanish and the Italians were the first to accept this "exotic" fruit (Oakeley *et al.,* 2015). It was consumed with oil, salt and pepper in Italy. In other European countries acceptance was slow and the tomato long remained an ornamental plant because of the fear of poisoning or "the curse of the dulcamara" (Oakeley *et al.,* 2015). This belief was associated with the toxic, hallucinogenic and aphrodisiac properties of other members of the Solanaceae, such as Belladona (*Belladona*) and Mandragora (*Mandragora*), which have detrimental effects on health caused by some alkaloids (Oakeley *et al.,* 2015).

The first mention of tomato in England was by the botanist Gerard in 1597. A German naturalist, first showed engravings of tomato plants present at the Eichstätt Garden in Germany. Considering the size of the fruit shown in the engravings, it is assumed that they depict plants already domesticated as ornamentals. In 1760, tomato was represented as an ornamental in the Andrieux-Vilmorin catalogue in France (Howell, 2010).

Tomato returned to the Americas in the 18th century, according to reports of its cultivation in the West Indies and the Caribbean. Tomato was also transported to North America in the 18th century by European colonists arriving at commercial harbours in New Jersey, the

United States (Andreas, 2013). The first written account dates from 1710, when it was registered as an ornamental plant by William Salmon. However, it was not trusted as a foodstuff in the United States until the beginning of the 20th century because of its similarity to certain poisonous fruits (Tarter, 2020).

Knowledge of the tomato's nutritional importance increased from the end of the 19th century to the beginning of the 20th century (Tarter, 2020). The first improved tomatoes were developed by Italian breeders in the 17th or early 18th century, who converted the small, wrinkled and hard tomato into the red coloured, smooth and juicy varieties known today (Hyman, 2019). Starting from these cultivars, the United States began in 1867 the production of various cultivars and nine commercial varieties (Early Smooth, The Cook's Favorite, Tildem, Powells Early, FEUE, Large Red, Large Yellow, Tree Tomato Red and Yellow Plum) (LeHoullier, 2014). Tomato is now a cosmopolitan crop with major production in temperate regions, even though its origins lay in tropical regions (Kroschel *et al.*, 2020).

2.5 Climate and soil

2.5.1 Temperature and light

Tomato requires a relatively cool, dry climate for high yield and premium quality. However, it is adapted to a wide range of climatic conditions from temperate to hot and humid tropical. The optimum temperature for most varieties lies between 21℃ and 24 °C. The plants can survive a range of temperatures, but the plant tissues are damaged below 10 °C and above 38 °C (Singh *et al.*, 2017).

Tomato plants react to temperature variation during the growth cycle, for seed germination, seedling growth, flower and fruit formation and fruit quality. If cool or hot weather spells persist during flowering, pollen production will be low (Rosbakh *et al.*, 2018). This will influence fruit formation. Frost will kill the plants. To avoid frost damage, it is best to wait until the winter is definitely over before sowing. It is possible to sow indoors earlier (in pots or trays). Light intensity affects the colour of the leaves, fruit set and fruit colour (Borghi *et al.*, 2019).

2.5.2 Soil type

Tomatoes grow well in a variety of soil textures, but commercial growers tend to prefer well drained sandy loam soil with high level of organic contents as best suitable for tomato cultivation. Soils with high acidity are not suitable for tomato cultivation. Three to four grams of suitable lime can be applied in the field in an interval of three years to reduce the level of acidity to tolerable limits. There is a need to go for soil testing at the beginning of the crop season (Shamshiri *et al.*, 2018).

Sandy soils drain better and warm up more readily than denser soils. Denser soils like loam and clay loam may also be used as long as the fields are carefully irrigated and well drained. Universally, all soil is prepared prior to planting using a variety of specialty equipment to improve the overall quality of the soil by breaking up clods and adding amendments (White, 2015).

2.6 Cultivation of tomato

2.6.1 Nursery practices

Viable tomato seeds are nursed and watered with other related nursery activities such as thinning out, fertilizer and insecticide application are carried out (Jacobson, 2018).

2.6.2 Field Planting

When the tomato seedlings are ready for transplanting, they are transferred and planted in their permanent fields, thus the Greenhouse and the open field (Yan *et al.*, 2019).

2.6.3 Agronomic practices

Cultural activities such as watering, fertigation, insecticide application, weeding, etc are carried out (Savvas and Gruda, 2018).

2.6.4 Yield of Harvesting

The total output (yield) is recorded at the end of project (Dietzenbacher *et al.*, 2013).

2.7 The importance and health benefits of tomatoes

Globe or slice tomatoes are known as round tomatoes and are mostly used in the preparation of dishes and for processing. Beefsteak tomatoes are very large and juicy, have thicker skins, shorter shelf life and are kidney-bean shaped, and mostly used for sandwiches and burgers (McNamee, 2017). For tomato paste and sauces, plum varieties are the best type as they contain lower water content and high solid contents (O'Shea *et al.*, 2012).

Cherry or cocktail tomatoes are used whole and often time used for salads because of their sweet taste; they are characteristically small and round (Van Wyk and Wink, 2018). The grape type which is slightly smaller than the plum type was recently discovered and is also used in salads (Zhu *et al.*, 2018). Pear shaped tomatoes are also sometimes grown. Other relevant types are the Campari, Tomberries, Oxheart, and Marzano (Aduhene-Chinbuah, 2018).

Tomatoes can make people healthier and decrease the risk of conditions such as cancer, osteoporosis and cardiovascular disease (Bhowmik *et al.*, 2012). People who eat tomatoes regularly have a reduced risk of contracting cancer diseases such as lung, prostate, stomach, cervical, breast, oral, colorectal, esophageal, pancreatic, and many other types of cancer (Kumar *et al.*, 2012).

Some studies show that tomatoes and garlic should be taken together at the same time to have its cancer preventive effects. Lycopene and the newly discovered bioflavonoids in tomatoes are responsible as cancer fighting agents (DiMarco-Crook and Xiao, 2015). Not only raw tomatoes but also cooked or processed tomato products such as ketchup, sauce, and paste, are counted as good sources of cancer prevention (Valderas-Martinez *et al*, 2016). Tomato is also good for liver health. Tomato has detoxification effect in the body. Probably it is due to the presence of chlorine and sulfur in tomatoes (Bhowmik *et al.*, 2012).

According to some studies, 51 mg of chlorine and 11 mg of sulfur in 100 grams' size of tomato have a vital role in detoxification. Natural chlorine works in stimulating the liver and its function for filtering and detoxifying body wastes. Sulfur in tomatoes protects the liver from cirrhosis (Kumar *et al.*, 2012). Tomato juice is known as good energy drink and for rejuvenating the health of patients on dialysis (Adejuwon, 2017).

Herbalists knew that taking tomatoes and tomato products could reduce the risk of cardiovascular diseases because of lycopene in it. Tomato prevents hardening of the arteries and can therefore reduce high blood pressure. Red ripened tomato is a powerful antioxidant. Vitamin E and lycopene in tomato prevents LDL oxidation effectively (Bhowmik *et al.*, 2012). Bean sprouts, cabbage or barley malt contain vitamin E. Tomato is an excellent fruit or vegetable for rapid skin cell replacement. Tomato juice can be used for healing sunburn because of its unique vitamin C. Tomato juice can be named as a good sports drink to restore fatigue and sleepiness (Adejuwon, 2017).

Tomatoes contribute to a healthy, well-balanced diet. They are rich in minerals, vitamins, essential amino acids, sugars and dietary fibres. Tomato contains much vitamin B and C, iron and phosphorus. Tomato fruits are consumed fresh in salads or cooked in sauces, soup and meat or fish dishes. They can be processed into purées, juices and ketchup. Canned and dried tomatoes are economically important processed products (Abolusoro and Abolusoro, 2017).

The fruit contains a large quantity of water, vitamins and minerals, low amounts of proteins and fats, and some carbohydrates. It also contains carotenes, such as lycopene (which gives the fruit its predominantly red colour) and *beta*-Carotene (which gives the fruit its orange colour) (Bhowmik *et al.*, 2012). Modern tomato cultivars produce fruits that contain up to 3% sugar of fresh fruit weight. It also contains tomatine, an alkaloid with fungicidal properties. The concentration of tomatine decreases as the fruit matures and tomatine concentration contributes to determining the taxonomy of the species. Thus, it can be useful in crop breeding for cultivated tomatoes (Motamedzadegan and Tabarestani, 2011).

Tomato is one of the best studied cultivated dicotyledonous plants at the molecular level and has been used as a model species for research into gene mapping, gene characterization (e.g. plant pathogen resistance genes) and gene transfer approaches. It is also useful to study other plant traits such as fruit ripening, hormone function and vitamin biosynthesis (Ercolano *et al.*, 2012).

2.8 Coco Peat

The coco peat, more correctly called coconut coir, is an organic matter used as a growth medium (soil) for propagation. This was made from the pith inside a coconut husk by beating and separated it into coconut fiber (Duke, 2018). The coco peat must be rehydrated before it can be used as a growing medium. It is naturally anti-fungal, making it an excellent choice to start seed. Coco peat is so environmentally friendly that means it is reusable. In a comparison of coco peat versus soil, the peat retains much more water and releases it slowly to plants roots (Mensah, 2015). The coco fiber is the brick type and mixed with soil to create air pores that bring oxygen to plant roots. It must always be moistened well and checked frequently to keep up on plant water needs (Blok *et al.*, 2019).

Coco peat has numerous benefits among which are: it is organic in nature, raw material is easily available, transportation is easy because its light in weight (Chauhan *et al.*, 2019). It is beneficial for both the plants and soil microorganism, improves soil fertility, increases soil porosity, increasing aeration which is beneficial to the plants. It also has long lasting biological effect in soil, etc. (Saba *et al.*, 2014).

2.9 Diseases in Outdoor Production

2.9.1 Early blight

Early blight, caused by the fungus *Alternaria solani*, is also known as Alternaria leaf spot or target spot. Like Septoria leaf spot, early blight is common in tomato plantings, and the two diseases may attack the same plants. Premature loss of lower leaves is the most obvious symptom of the disease (Shahid *et al.*, 2017). Brown to black spots, increases with time in diameter with dark edges, appear on lower leaves. Spots frequently merge, forming at early stage during the growing season but usually progresses most rapidly after plants have set fruit. Cultural and chemical controls for early blight are the same as Septoria leaf spot. Resistant varieties of tomatoes in the Mountain series (Mountain Supreme, Pride, Gold, Fresh, and Belle) provide partial resistance (Singh, 2018).

2.9.2 Anthracnose

Anthracnose, caused by the fungus *Colletotrichum coccodes*, is probably the most common fruit-attacking disease of tomato. Symptoms first become visible on ripe or ripening fruit as small, circular, indented spots in the skin. As these spots expand, they develop dark centers or concentric rings of dark specks, which are the spore-producing bodies of the fungus (Gleason and Edmunds, 2015).

Most flowering affected plants die early and produce few, if any, fruits which split open. Infected stem reveals brownish streaks extending up and down the stem. These discolored streaks are the water-conducting tissue, which becomes plugged during attack by the fungus, leading to wilting of the leaves (Pankaj *et al.,* 2020). Control measures for anthracnose are the same as for Septoria leaf spot (Gleason and Edmunds, 2015).

2.9.3 Fusarium wilt

The fungus that causes Fusarium wilt, attacks only certain tomato cultivars. Plants infected by this soil-dwelling fungus show leaf yellowing and wilting that progress upward from the base of the stem. Initially, only one side of a leaf midrib, one branch, or one side of a plant will be affected. The symptoms soon spread to the remainder of the plant. Wilted leaves usually drop prematurely (Vethavalli & Sudha, 2012; Luo *et al.*, 2015). Planting disease-free seed or transplants in well drained, disease-free soil, practice four-year crop rotation system excluding tomatoes to reduce the population of fungi in the soil. Affected plants are removed and destroyed. In the Greenhouse and seed beds, infested soils are treated with steam before used (Shankar *et al.*, 2014).

2.9.4 Bacterial spot

Bacterial spot, caused by the bacterium *Xanthomonas campestris* pv. *vesicatoria,* infects both tomato and pepper. Spots that appear on leaves and stems are small (up to ⅛ inch across), circular to irregular in shape, and have a slightly greasy feel (Gleason and Edmunds, 2015). Unlike similar-sized spots caused by the fungus *Septoria lycopersici*, those caused by the bacterial spot pathogen do not develop grayish brown centers. As lesions enlarge, they often become surrounded by a yellow halo.

If spots are numerous, they begin to grow together, and leaves wither and turn brown (Narayanasamy, 2011). Fruit symptoms are more distinctive than leaf or stem symptoms. Spots on green fruit first appear as black, raised, pimple-like dots surrounded by water-soaked areas. As the spots enlarge, they become gray-brown and scabby with sunken, pitted centers (Srivastava *et al.,* 2014). The bacterium overwinters on the surface of seeds, in infected debris, and in soil. It is commonly brought into fields on infected transplants. Warm, rainy weather favors rapid spread of bacterial spot (Pankaj *et al.*, 2020).

Control measure can be by obtaining disease-free transplants since the bacteria can be transmitted to seedlings from contaminated seeds. It is advisable to avoid rotating with peppers and also avoid handling plants (pruning and tying, for example) any more than is necessary, because wounds caused by handling allow bacteria to enter plants. Sprays of a fixed copper product can reduce spread of the disease in the garden if applications begin when first symptoms appear (Shankar *et al.,* 2014).

2.9.5 Bacterial speck

This disease, caused by the bacterium *Pseudomonas syringae* pv. *tomato,* does not affect pepper or other solanaceous crops but may survive on non-host plants. Tiny dark spots appear on leaves, surrounded by yellow halos. However, as with bacterial spot and bacterial canker, the fruit symptoms are most characteristic. The numerous specks that develop on young green fruit are slightly raised and have well-defined margins (Pankaj *et al.*, 2020). The specks are considerably smaller than the spots caused by bacterial spot, do not penetrate the fruit deeply, and can be scraped off with a fingernail (Ruocco *et al.*, 2010). Although bacterial speck seldom reduces yields greatly, it can harm fruit quality. Infection is favored by cold (less than 21°C), wet conditions. Epidemics often follow rainstorms that cause abrasion of leaves and splash soil onto the foliage (Pouliot, 2018).

2.9.6 Bacterial canker

Bacterial canker, caused by the bacterium *Clavibacter michiganensis subsp. Michiganensis*, has caused serious losses in some tomato plants in the North Central states in the USA, during the last few decades. Young transplants may wilt suddenly (Vallad *et al.*, 2018; Chen *et al.*, 2019). On older plants, leaflets begin to turn brown at the edges, then die back progressively toward the leaf midrib. Often only one side of a leaflet or a plant develops symptoms first, but symptoms eventually spread. Rarely, cavities may develop within stems, sometimes splitting open into brown, longitudinal cankers (Smith, 2012).

Spots on fruit are quite distinctive: white and slightly raised at first, then raised, dark-colored centers with white halos. These spots are sometimes termed “bird’s-eye” lesions. The white halo turns brown as the spot becomes older (Aysan and Horuz, 2015). Control measures for bacterial canker are the same as for bacterial speck, except that copper sprays have minimal impact on slowing the spread of bacterial canker (Monchiero *et al.*, 2015)

2.9.7 Viruses

The most common viral disease is tomato spotted wilt virus (TSWV), but others can occur. TSWV causes distinctive yellow ring spots on mature fruit. Foliage also can be affected; plants are usually stunted and tip leaves show a purplish discoloration. Thrips are small green-brown insects, spread the virus. Plants can be affected as transplants while growing in a greenhouse; after transplanting, stunting and failure to set fruit may be the most noticeable symptoms (Pankaj *et al.*, 2020).

Other viruses are spread by aphids or leafhoppers and can cause leaf curling, yellow or green mosaic patterns on the leaves, “shoe stringing” of leaves, or a bronzing appearance. Fruits also are affected with mosaic patterns, streaking, or mottled areas (Dijkstra and de Jager, 2012). Planting only certified virus-free transplants is the best technique for managing viruses. It is helpful to verify that the greenhouse used to produce transplants conducts a vigorous program to control aphids and thrips (Nicola and Pignata, 2018).

There is no way to “cure” a virus infected plant. However, removing the infected plant as soon as symptoms are found can help prevent spread by insects to healthy plants. Many viruses that infect tomato also infect peppers and potatoes; so, planting these crops next to each other should be avoided. Insect control may also be beneficial in the transplant and early-season phases. Consult *Insects and Diseases in the Home Vegetable Garden* (PM 230) for current insecticide recommendations (Gould, 2013).

2.10 Diseases in Greenhouse Production

2.10.1 Gray mold

Gray mold, caused by the fungus *Botrytis cinerea,* is a common disease of greenhouse-grown tomatoes. This disease is characterized by a light-gray fuzzy growth that appears on stems and leaves. Soft rot of the stem end of the fruit can also occur. Botrytis infections are most severe in greenhouses with moderate temperatures, high humidity, and stagnant air. Increasing ventilation and air circulation to reduce humidity levels as well as timely fungicide applications are recommended (Mtasa *et al.,* 2014).

2.10.2 Leaf mold

Leaf mold, caused by the fungus *Fulvia fulva,* can cause problems in humid greenhouses with poor air circulation. This fungal disease appears on lower leaves as yellow spots on the upper surface and fuzzy masses of buff-colored spores on the underside. These leaves drop prematurely as the disease progresses upward on the plant. Lowering greenhouse humidity, planting resistant varieties, and applying fungicide promptly can be helpful in leaf mold management (Ruocco *et al.,* 2010).

2.10.3 Powdery mildew

Powdery mildew, caused by the fungus *Oidium neolycopersici,* is also common in humid greenhouses with poor air movement. Characterized in the early stages by white patches on the upper surface of leaves, this disease can cause defoliation as the spots develop into brown lesions. Increasing air circulation and spacing between plants will reduce powdery mildew problems (Shankar *et al.,* 2010). Fungicide sprays also can be effective if used when symptoms are first noticed. Good control of powdery mildew can be achieved by using several fungicides. Fungicides are most effective when sprays begin as soon as the first symptoms are noticed, rather than after the disease is already well established (Gessler *et al.*, 2011).

2.11 Physiological disorder

2.11.1 Blossom end rot

Blossom end rot is a very common problem on green and ripe tomatoes. It first appears as a sunken, brownish black spot on the blossom end of the fruit. These spots may gradually increase in size. Although blossom end rot itself causes only local injury, secondary organisms frequently invade (Bartz *et al.*, 2013)**.** Blossom end rot lesion spreads and cause complete rotting of the fruit. It often occurs in rapidly developing fruit during periods of hot, dry weather and tends to have the greatest impact on the earliest maturing fruit (Wills and Golding, 2016).

Blossom end rot is caused by a calcium deficiency that is related to wide fluctuations in available moisture. To prevent blossom end rot, maintain a steady rate of plant growth without stress. A consistent and ample supply of moisture can reduce the problem by helping to maintain a steady flow of calcium from the soil to the fruit (Gleason and Edmunds, 2015). Mulching also will help by conserving soil moisture. Blossom end rot is more serious where there is excess of nitrogen fertilizer being applied. Staking and pruning tomato plants also may increase the incidence of blossom end rot. If blossom end rot occurs the affected fruit should be removed so that later-maturing fruit will develop normally.

Mulching and avoiding heavy applications of nitrogen fertilizer may help reduce fruit cracking (Dreistadt, 2016).

2.11.2 Fruit cracking

Two types of cracks may develop on tomato fruit. Radial growth cracks radiate from the stem, and concentric cracks encircle the fruit, usually on the shoulders. Similar to blossom end rot, cracking is associated with rapid fruit development and wide fluctuations in water availability to the plant (Cao, 2012).

Fruit that has reached the ripening stage during dry weather may show considerable cracking if the dry period is followed by heavy rains and high temperatures. Tomato varieties differ considerably in the amount and severity of cracking under climatic conditions (Khadivi-Khub, 2015). Supersonic and Jet star are two varieties that show relatively low incidence of cracking. As with blossom end rot, mulching and avoiding heavy applications of nitrogen fertilizer should help reduce fruit cracking (Gleason and Edmunds, 2015).

2.11.3 Cat faced fruit

Cat facing is a term used to describe misshapen fruit with irregular bulges at the blossom end and bands of leathery scar tissue. Cold weather at the time of blossom set distorts and kills certain cells that should develop into fruit, resulting in the deformities. The disorder is most often observed among first-formed fruit. Catfacing is most common in the large-fruited “beefsteak” type of tomatoes (Wright, 2020).

2.11.4 Sunscald

Sunscald occurs on green tomato fruit exposed to the sun. The initial symptom is a whitish, shiny area that appears blistered. The killed, bleached tissues gradually collapse, forming a slightly sunken area that may become pale yellowish and wrinkled as the fruit ripens. The killed tissue is quickly invaded by secondary organisms and the fruit decays (Amartey, 2013).

According to Racsko and Schrader (2012), fruits most subject to sunscald are those that have been exposed suddenly to the sun because of pruning, natural spreading of the plant caused by a heavy fruit load, or loss of foliage from diseases. The extent of the injury is more serious during periods of abnormally high temperatures. To prevent sunscald on tomato fruits, foliar disease should be controlled and heavy pruning or shoot removal avoided.

2.11.5 Blotchy ripening

This physiological disorder is indicated by the absence of normal red pigment on localized areas of the fruit. These areas appear as yellow or gray-green patches on otherwise normal-colored ripening fruit. When these fruits are sliced open, brown discoloration is often apparent (Gleason and Edmunds, 2015).

Climatic, nutritional and cultural problems may contribute to blotchy ripening. Low levels of potassium in plants and prolonged cloudy periods or inadequate light intensity have been associated with the disorder. Other possible contributing factors are high soil moisture, high humidity, low temperature, soil compaction and excessive fertilization (Gleason and

Edmunds, 2015). These environmental factors can contribute to nutrient deficiencies or other imbalances that impede development of red pigment in the fruit. To minimize incidence of blotchy ripening, proper cultural practices to maintain nutritional balance and plant vigor should be followed. If commercial fertilizers are used, balanced formulations should be selected and over-application avoided (Gleason and Edmunds, 2015).

2.11.6 Physiological leaf roll

Leaf roll occurs when the edges of the leaves roll upward and inward. Sometimes the curling continues until the leaf margins from either side touch or overlap. Some leaves on the plant may not exhibit rolling. Leaf roll does not reduce plant growth and yield, or fruit quality (Rivière *et al.*, 2017). It is believed to result from irregular water supply, and may be intensified following pruning. The symptoms are sometimes temporary, disappearing after a few days, but can persist throughout the growing season (Chefetz, 2015).

2.11.7 Failure to set fruit

High summer temperatures can reduce the number of tomato fruit harvested in several ways. High day and night temperatures will reduce flower formation on tomato plants. If the night temperatures are above 13 °C, flower formation and pollination are reduced. High temperatures for several consecutive days, coupled with drought conditions, will lead to poor pollination and cause flowers to drop from the plants (Hatfield and Prueger, 2015). Hot drying winds may intensify the problem. Plants sometimes drop their flowers when night temperatures are lower than 55 °C. The most favorable night range of temperatures for tomato fruit set is between 23 °C and 25 °C. Commercially available blossom-set hormones should not be relied upon because they do not give consistent results (Kelley *et al.*, 2010).

2.11.8 Herbicide injury

This malady is caused by misapplication or drift of 2,4-D, MCPP, and other growth regulator herbicides. Tomato plants are highly sensitive to these chemicals throughout the growing season (Gleason and Edmunds, 2015). The first symptom is downward curling of leaves and tips of growing points. Leaves often become narrow and twisted toward the tip, with prominent, light-colored veins. The symptoms are most pronounced on portions of the plant that were actively growing when the exposure occurred. In severe cases, stems and petioles become thick, stiff, and brittle with warty outgrowths. Affected plants usually recover. However, the fruit may become catfaced or develop in a plum shape, and may be hollow and seedless (Bethke *et al.*, 2014).

To avoid herbicide injury, spraying when the environment is windy should be avoided. In addition, spraying should be done at low pressures, a coarse-spray nozzle should be used and applied as close to the ground as possible (Creech *et al.*, 2015). Apply cations other pesticides in sprayers that have previously contained herbicide should be avoided because traces of herbicide are likely to remain in the sprayer even after thorough rinsing (Creech *et al.*, 2015).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of The Project Site

The experiment was conducted at the Multi-Purpose Nursery of the University of Education Winneba (now AAMUSTED), Mampong –Ashanti. Mampong lies at the transitional zone between the forest and northern savanna zones of Ghana. Mampong lies at 57.6 km North of Kumasi on latitude 07 ^{o} 04' N and longitude 01 ^{o} 024' W of the equator and it is 457.5 m above sea level (Ghana Meteorological Agency, 2008).

Mampong has a bimodal rainfall pattern with annual mean rainfall between 1094.4 mm and 1200 mm and the monthly mean rainfall of about 91.2 mm. The major rainy season occurs from March to July whereas the minor rainy season occurs from September to November (Ghana Meteorological Agency, 2008). Mampong has a daily temperature of about 30.5 ^{o}C. The experiment lasted for 12 weeks (84 days) and was started on the 23rd of August, 2019 to end on the 23rd of November, 2019.

3.3 Acquisition of Materials and Sources

(a) Tomato seeds

Tomato seeds were brought from Accra, Ghana Nirit Seeds LTD. The variety of tomato sown was TYTANIUM F1.

(b) Buckets

A total of ninety (90) pots were bought from Mampong market on the 21st of August, 2019 for the purpose of this project as containers. The buckets were perforated at the bottom on the next day each having at least five holes for aeration and draining of excess water. The size of holes per bucket was 1 cm.

(c) Polythene Sheets

Plain, transparent polythene sheets were also bought from Mampong market on the same day. These sheets were spread to cover the soil surface to prevent soil borne diseases from entering into the pots.

(d) Funnels

Two funnels were bought from the market to be used as improvised rain gauge in the open field to calculate for the water difference when it rains.

(e) Voltic bottles

Three Voltic bottles of 2 L capacity were also connected together with the funnel to be used as improvised rain gauges.

3.4 Experimental designed and treatments

3.4.1 Layout of experimental plots

Two experimental lines consisting of forty-five pots each were monitored under the two treatments (i.e. Greenhouse and open field environments). Calibration of water drip lines were done in both environments on the 29th August, 2019 at 4: 38pm with cut Voltic water containers of 2 L.

3.5 Cultural practices

3.5.1 Land preparation

The land for the project was cleared on the 19th day of August, 2019 with cutlasses and hoes. The land was further raked for even soil surface on the next day with rake.

3.5.2 Nursery

The seeds were sown in the seedbed at the nursery site in the Greenhouse on the 23rd July, 2019. The seed nursed was one in a hole. By the eighth day after sowing 95% of the seeds had germinated.

3.5.3 Planting

One seedling or one tomato plant was put in each of the ninety plastic pots as the planting number per pot. The pH of the coco peat was around 5.5-6.8.

3.5.4 Transplanting of seedlings

The tomato seedlings were transplanted on the 23rd of August, 2019 in both the Greenhouse and in the open field.

3.5.5 Weed control

Weeds constitute big nuisance as they compete with the crop for nutrients in the soil and can also harbour insects and diseases that cause harm to tomatoes.

Weed control was manually done using cutlasses, hoes and hands. The clearing of the land was done on the 20th August, 2019 and since *Cyperus spp* were the common weeds, subsequent weeding was carried out on weekly basis till the project was over.

3.5.6 Fertilizer application

Fertigation chemicals used for this project were calcium nitrate plus mono ammonium phosphate mixed and potassium nitrate plus magnesium sulphate. Potassium nitrate, 4 kg to magnesium sulphate of 3.2 kg per 1000 litres of water and 3.2 kg of calcium nitrate to mono ammonium phosphate of 0.7 kg per 1000 litres of water.

3.5.7 Watering

The first watering was done on the 23rd August, 2019 immediately the seedlings were transplanted to both the Greenhouse and the open field. Watering was done every morning and evening through drip lines for twenty (20) minutes at the delivery rate of 90 litres of water per irrigation.

3.5.8 Pest and disease control

Pests and diseases were controlled using Chemaprid 88EC (20ml/8 litres of water) and D-Lion® Fungi 2020 (Copper hydroxide 77 % WP). Subsequent fumigation was carried out every two weeks.

3.5.9 Harvesting

The first harvesting was done on the 10th day of November, 2019 by hand picking and was followed by subsequent harvesting for two times for every ten days intervals.

3.6 Data collection

Data collection started four weeks after transplanting. Growth measurement was taken once in every seven days for five weeks while yield measurement was taken at the time of harvest.

3.6.1 Plant Height

Five plants were picked at random from each treatment plot and tagged. Height of each experimental plant in both environments were taken using a meter rule to measure from the base of the stem to the apical leaf weekly for five (5) weeks. The average mean height of each experimental plant in each pot was taken with respect to treatment.

3.6.2 Number of leaves

All fully matured leaves were counted. The average mean for each environment was calculated.

3.6.3 Number of fruits

The total number of fruits harvested from each pot was counted and the average mean for each environment calculated.

3.6.4 Fruit length

The length of all fresh fruits harvested from each environment was measured using vernier caliper and the average mean for fresh fruit for each environment was determined.

3.6.5 Fruit weight

The weight of each fruit selected from the experimental plots were taken using weighing scale. The average mean weight of each experimental fruit on each environment was taken with respect to the environment.

3.6.6 Fruit diameter

The vertical diameter of fruit selected from experimental plant on each environment was taken using the vernier caliper.

3.7 Analysis of data

The data was analyzed with the student T-test and the separation of means carried out using the least significant difference (LSD) test.

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of Greenhouse Technology on Plant Height (cm)

Figure 4.1 shows the effect of greenhouse technology on tomato plants height.

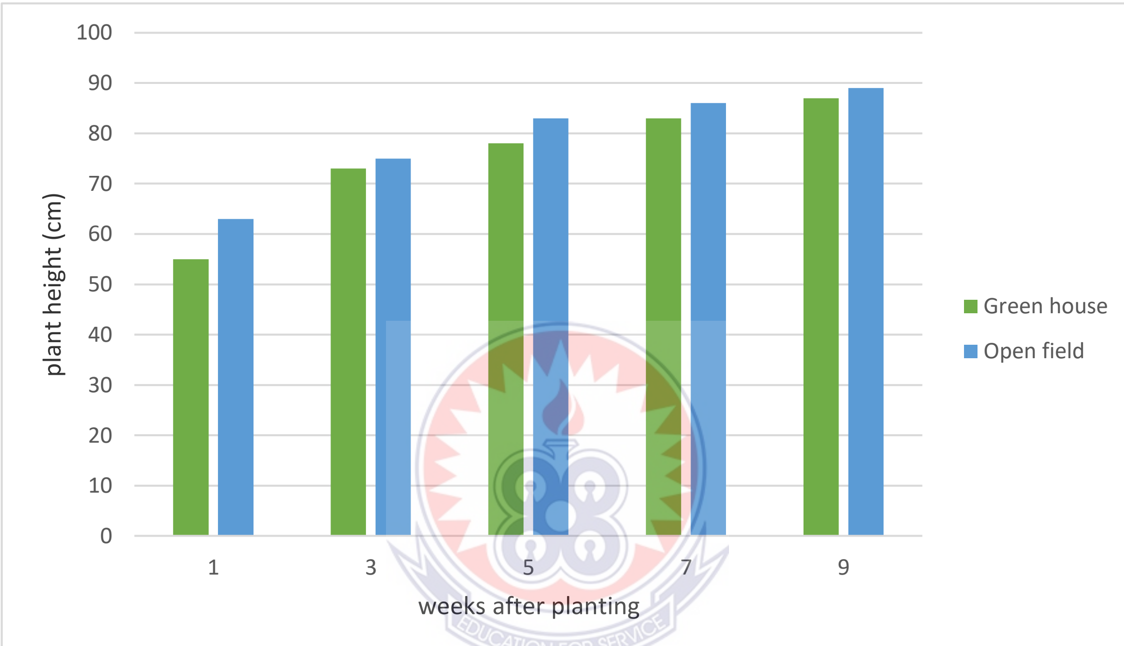

Figure 4.1: Effects of greenhouse technology on plant height (cm) of tomato

The results revealed in plant height among tomatoes grown under greenhouse and open field technology across the period of study (Figure 4.1). The taller plants at 1 week were observed from the open field while the greenhouse technology recorded shorter plants. Also, at 3, 5, 7 and 9 weeks after planting, tomato plants grown in the open field recorded taller plants compared to the tomato plants grown under greenhouse technology.

4.2 Effects of Greenhouse Technology on Number of Branches

Figure 4.2 shows the effect of greenhouse technology on the number of branches produced over the period of study. Results from the study revealed that number of branches were influenced by the greenhouse and open field technologies.

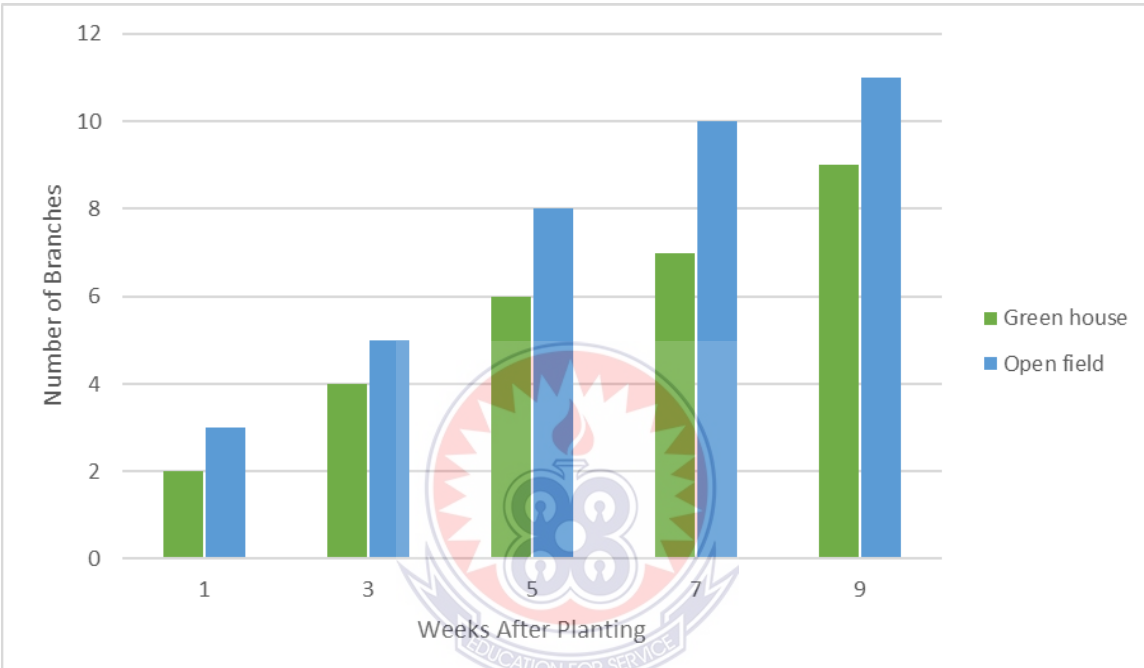

Figure 4.2: Effects of greenhouse technology on number of branches of tomato

Number of branches produced at 1, 3, 5, 7 and 9 weeks after planting were higher among tomato plants grown in the open field and lower among tomato plants grown under the greenhouse technology (Figure 4.2).

4.3 Effects of Greenhouse Technology on Stem Girth (cm)

Figure 4.3 shows the effect of greenhouse technology on tomato stem girth. Results from the study show differences among tomatoes stem girth grown under greenhouse and open field technology across the period of study.

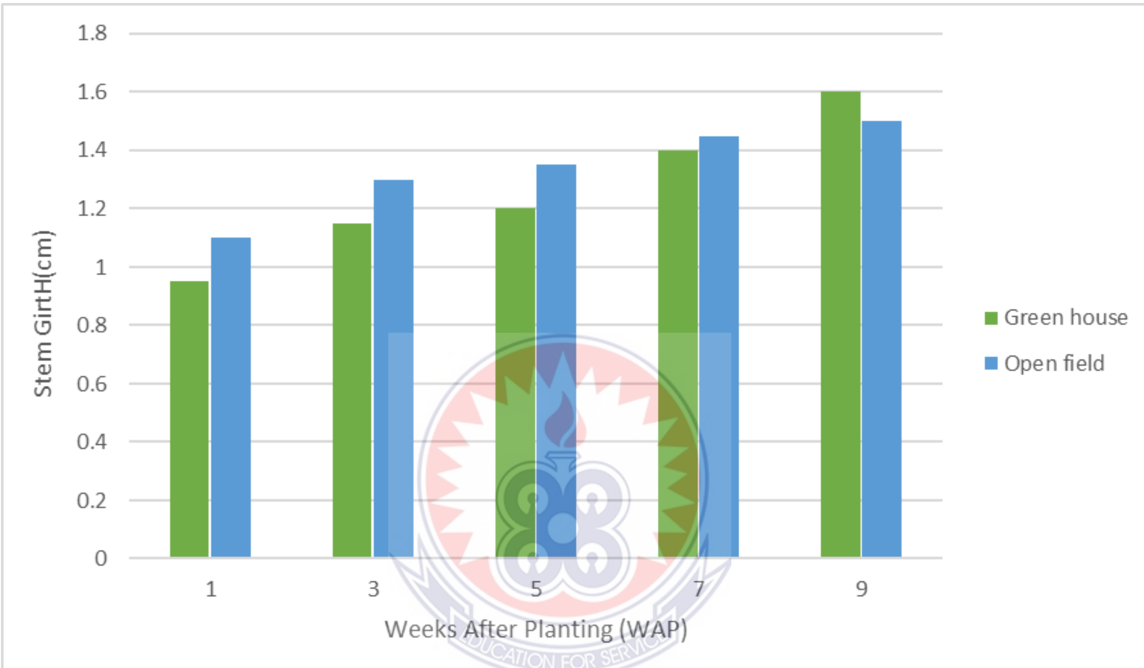

Figure 4.3: Effects of greenhouse technology on stem girth (cm) of Tomato.

Tomatoes grown in the open field recorded the higher stem girth in comparison with tomato plant grown under the greenhouse technology at 1, 3, 5 and 7 weeks after planting. However, at 9 weeks after planting, tomato plants grown under the greenhouse technology recorded the higher stem girth in comparison with tomatoes grown in the open field (Liu *et al.*, 2018).

4.4 Effects of Greenhouse Technology on Number of Flowers

Figure 4.4 shows the effect of greenhouse technology on number of flowers produced by the tomato plants. Results from the study show that, greenhouse and open field technology had effect on the number of flowers produced by the plants.

Figure 4.4: Effects of greenhouse technology on number of flowers

Tomato plants grown under greenhouse technology recorded the higher number of flowers in comparison with the open field at 1, 3, 5, 7 and 9 weeks after planting.

4.5 Effects of Greenhouse Technology on Number of Fruits Harvested

Figure 4.5 shows the effect of greenhouse technology on the number of fruits harvested. Results from the study show that, greenhouse and open field technology had effect on number of fruits harvested across the days of harvesting.

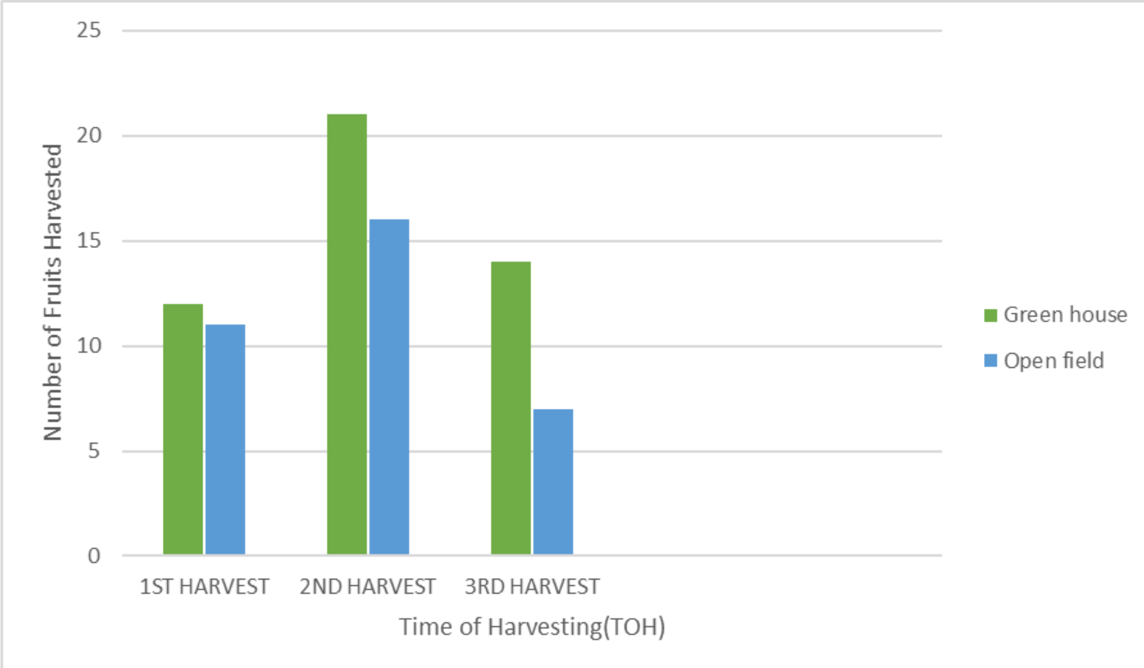

Figure 4.5: Effects of greenhouse technology on number of fruits harvested

The results revealed that, at 1, 2 and 3 days of harvesting, tomato plants grown under the greenhouse technology recorded the higher number of fruits in comparison with tomato plants grown in the open field.

4.6 Effects of Greenhouse Technology on Harvested Fruit Weight (g)

Figure 4.6 shows the effect of greenhouse technology on harvested fruit weight. Results from the study show that, greenhouse and open field technology had effect on harvested fruit weight across the days of harvesting.

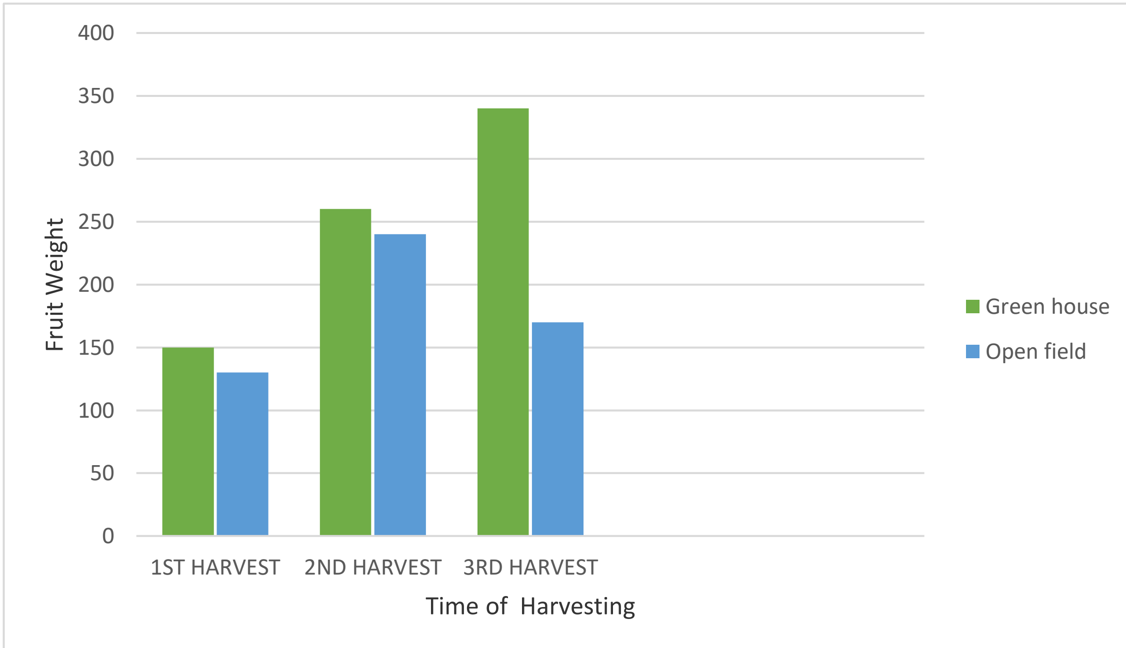

Figure 4.6: Effects of greenhouse technology on harvested fruit weight(g)

Figure 4.6 shows that, at 1, 2 and 3 days of harvesting, tomato plants grown under the Greenhouse technology recorded higher harvested fruit weight in comparison with tomato plants grown in the open field.

4.7 Effects of Greenhouse Technology on Number of Mature Vertical Fruit Length (cm)

Figure 4.7 shows the effect of greenhouse technology on mature vertical fruit length. Greenhouse technology had effect on the number of matured vertical fruit length.

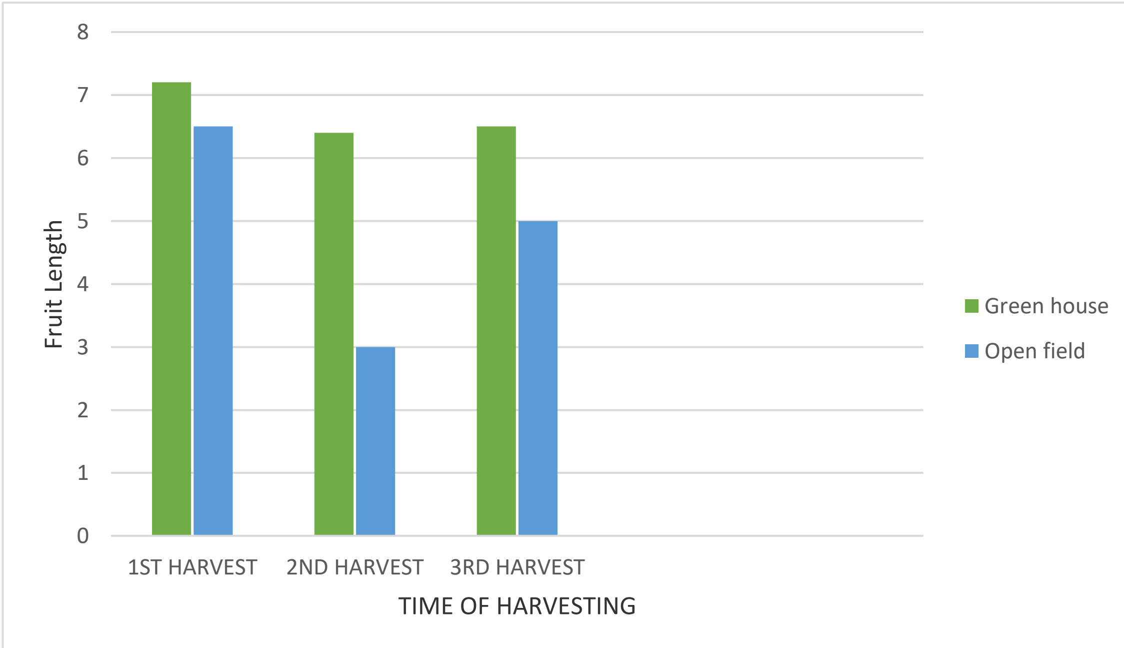

Figure 4.7 Effects of greenhouse technology on number of mature vertical fruit length

Figure 4.7, shown that at 1, 2 and 3 days of harvesting, tomato plants grown under the greenhouse technology recorded higher vertical fruit length as compared with tomatoes plants grown in the open field.

4.8 Effects of Greenhouse Technology on Mature Vertical Fruit Diameter

Figure 4.8 shows the effect of greenhouse technology on vertical fruit diameter. Results from Figure 4.8 show that, greenhouse and open field technology had effect on the vertical fruit diameter.

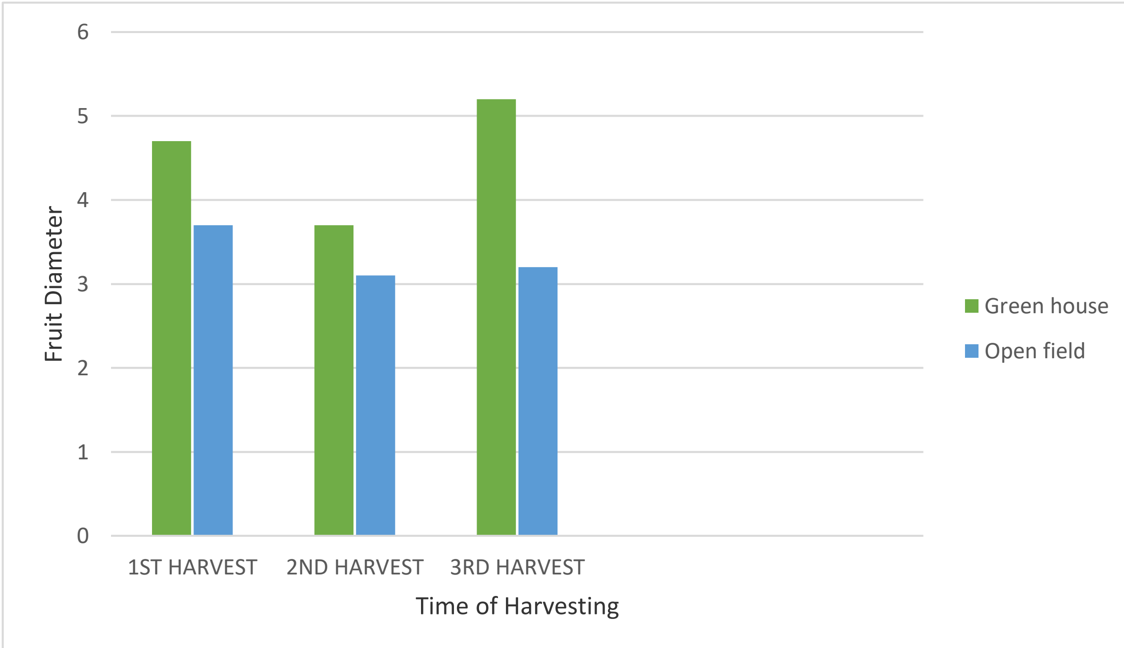

Figure 4.8 Effects of greenhouse technology on mature vertical fruit diameter

The results revealed that, at 1, 2 and 3 days of harvesting, tomato plants grown under the Greenhouse technology recorded higher fruit diameter in comparison with tomatoes plants grown in the open field.

4.9 Cost of Production, Income and Profit in Tomato Production

Tomato production under greenhouse technology had effects on the production cost, income, profit generated from the sales of harvested fruits and value – cost ratio. (Figure 4.9 and 4.10)

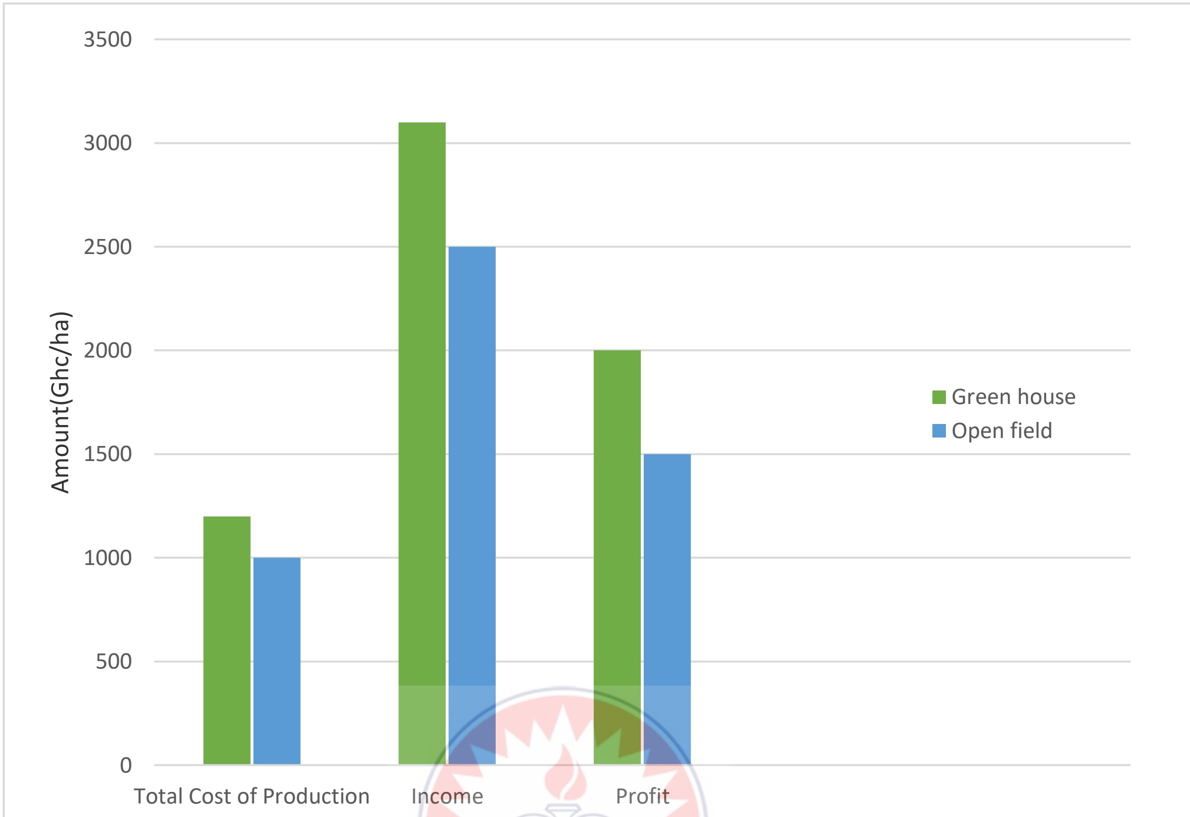

Figure 4.9 Cost of production, income and profit in tomato production under greenhouse and open field technologies

There was higher cost of production of the tomatoes under the Greenhouse taking into consideration the cost of the Greenhouse facility as compared to the open field. However, income margin after the sales of the tomato fruits was also higher in the Greenhouse technology as compared to the open field due to the adorable nature and the quantities of fruits harvested in the Greenhouse technology.

4.10 Value- cost ratio (VCR) in Tomato Production

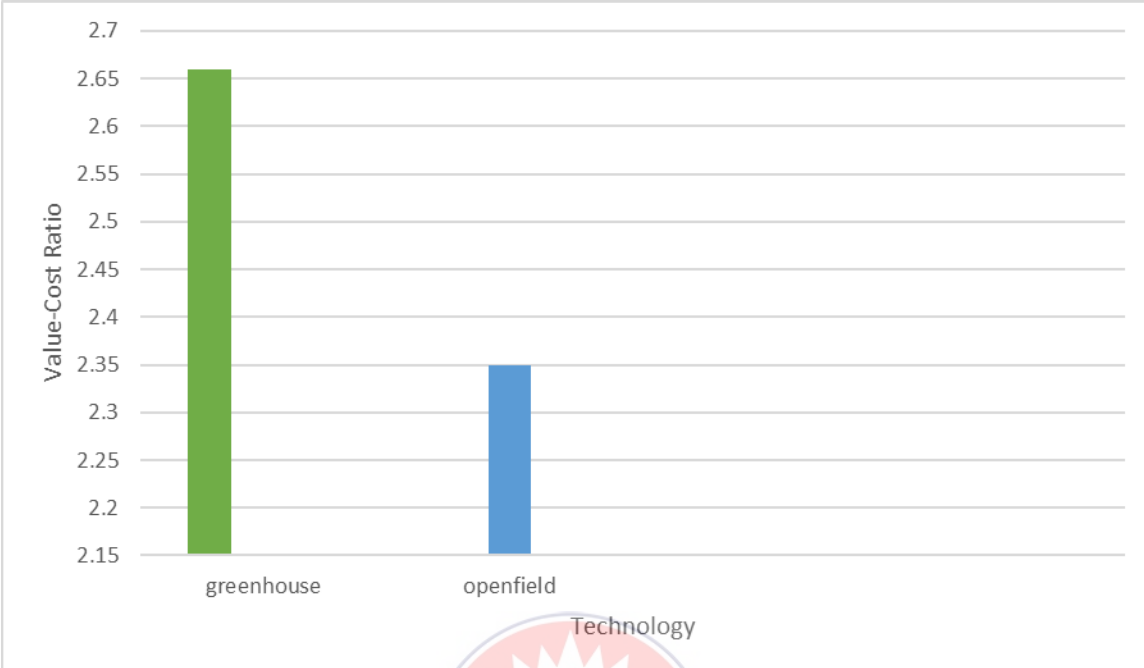

Figure 4.10 Value- cost ratio (VCR) in tomato production under greenhouse and open field technologies.

It is evident from figure 4.10 that the bar for Greenhouse technology on the value cost ratio is higher than that of the open field.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Plant Height

Variation showed in plant height could be attributed to the abiotic factors such as water (moisture), temperature, sunlight, etc. In this study, the average moisture content under the open field was higher due to the additional rains tomatoes under open field received as against the Greenhouse, hence higher plant height recorded under open field than the Greenhouse. Same conclusions were reported by Kinark *et al.* (2001) who found out at higher temperature the plant height grows faster and also the time elapsing between anthesis and ripe fruit will be shorter than at lower temperature. Results are in conformity with those of Kinark *et al.* (2001) under open field conditions. In this study, the average temperature within the day was higher in the open field which promoted higher production of plant growth hormones making the plants to grow more quickly (Tall) as compared to tomato plants grown under greenhouse technology

However, results of the study disagree with the findings of Kumar *et al.* (2007) who reported that tomato heights were suitable under greenhouse conditions than in open field. The differences in plant height observed in the study could be attributed to the differences in the changes of environment.

5.2 Number of Branches

The increase in the number of branches of tomatoes cultivated in the open field as compared to the Greenhouse could be attributed to the fact that number of branches per tomato increased with additional rains (moisture), light intensity and higher temperature in the open fields as reported by Kubota *et al.* (2018).

The increase in the number of branches of tomato plants cultivated in the open field as compared to the Greenhouse technology could be explained that number of branches per tomato plants increased with increasing daily temperature in the field as reported by Kubota *et al.* (2018). Again, this could be further explained that in the open field, temperature and sunlight values were higher as compared to the greenhouse during the period of study. Aduhene-Chinbuah (2018) reported that temperature and sunlight were higher in the open field as compared to the greenhouse and this influenced photosynthesis and transpiration resulting in the plant producing more branches. Similar findings were reported by Aduhene-Chinbuah (2018) who observed higher number of tomato branches in the open field as compared with tomatoes grown in the greenhouse technology. The differences in number of branches observed in this study and other researches could be as a result of prevailing environmental conditions as well as nutrients in the soil.

Results are in conformity with those of Eklund (2005) under open field conditions.

However, results of this study contradict with the findings of Odame (2009) who reported higher number of branches (stems) in tomatoes grown in greenhouse technology as compared with the open field. The differences in the number of branches observed in the study could be attributed to the differences in the change of environment. It is expected that tomato plants with higher number of branches should have higher quantities of tomato fruits if all things being equal.

5.3 Stem Girth

The higher stem girth observed among tomatoes grown in the open field could be attributed to the higher additional rains (moisture), light intensity and higher temperature (Kinark *et al.*, 2001). This could be explained that as moisture and temperature increases, photosynthesis as well as evapotranspiration also increases resulting in higher stem development. However, thicker stems indicate excessive vegetative growth and are usually associated with poor fruit set and low productivity.

5.4 Number of Flowers

According to Csizinsky (2005) higher temperature and low relative humidity have a generative effect on the number of flowers because they make water less available resulting in slow growth hence lower number of flowers in open field than in Greenhouse technology. However, results of the study contradict with the findings of Kubota *et al.* (2018) who reported higher number of flowers of tomatoes grown in the open field as compared to tomatoes grown in the Greenhouse technology. It is expected that tomatoes with the higher number of flowers should have higher quantities of tomato fruits, if all things being equal, and would have direct impact on the income of the farmer.

5.5 Number of Fruits Harvested

This could be attributed to the fact that, the number of flowers produced were able to develop into fruits due to the favourably controlled conditions in the Greenhouse. Results of the study are in conformity with those of Bailey (2002) who reported higher number of fruits harvested in Greenhouse than in open field. Results of the study also conform with those of Csizinsky (2005) who reports temperatures above 27 °C would considerably affect number of fruits harvested and it was evident in the open field where temperatures recorded were above 27°C. Number of harvested fruits determine the income level of the farmer and in this study the farmer of the Greenhouse technology would have higher income than the open field farmer.

The higher number of fruits observed among tomato plants grown under the greenhouse technology could be attributed to the higher number of flowers produced as reported in this study (Figure 4.4).

5.6 Harvested Fruit Weight

Higher fruit weight observed in tomatoes grown in the Greenhouse technology could be attributed to the controlled environment in the Greenhouse as compared to the open field. This could be explained that tomatoes require optimum temperatures (not too high or too low temperatures) during vegetative stage (Liu *et al.*, 2018). However, results of the study contradict with the findings of Adams *et al.* (2002) who reported higher fruit weight in the open field as compared to the Greenhouse technology because of the lower night temperatures inside the Greenhouse.

Prices of commodities on the market are determined by the size and weight of the commodity so from this study, greenhouse tomatoes would have higher prices than the open field with respect to the fruit weight and this would increase the income of the Greenhouse farmer

5.7 Mature Vertical Fruit Length and Fruit Diameter

Higher vertical fruit length observed in tomatoes grown in the Greenhouse technology could be attributed to the controlled conditions in the Greenhouse as compared to the open field. This could be explained that, tomatoes grown in Greenhouse have bigger fruit sizes, hence higher vertical fruit length as compared to tomatoes grown in the open field due to the controlled nature of the abiotic factors

However, results of the study contradict with the findings of Adams *et al.* (2002) who reported higher vertical fruit length in the open field as compared to the Greenhouse technology. The difference in vertical fruit length observed could be attributed to the differences in the changes of the environment.

Results of the study confirms the findings of Kinark *et al.* (2001) who reported higher vertical fruit diameter among tomatoes grown in the Greenhouse technology as compared to tomatoes grown in the open field. On the average, researches made on the vertical fruit diameter under both Greenhouse and open field suggested higher vertical fruit diameter in Greenhouse as compared to the open field and could be attributed to the differences in the environmental conditions of a place (Marcelis *et al.*, 2002).

5.8 Production Cost, Income and Profit

There was higher cost of production of the tomatoes under the Greenhouse taking into consideration the cost of the Greenhouse facility as compared to the open field. Income margin after the sales of the tomato fruits was also higher in the Greenhouse technology as compared to the open field due to the adorable nature and quantities of fruits harvested in the Greenhouse technology.

Results of the study confirms to the findings of Kinark *et al.* (2001) who reported higher income margin among tomatoes grown under controlled conditions as compared to open field.

CHAPTER SIX

SUMMARY CONCLUSION AND RECOMMENDATIONS

6.1 Summary

It was clear that the open field recorded higher values during the vegetative stage as compared to the greenhouse. However, during the reproductive stage the greenhouse rather recorded higher values as against the open field. This could be attributed to the controlled nature of the greenhouse.

6.2 Conclusion

1. The study concludes that greenhouse technology increased the yield of tomatoes as compared to open field.
2. Greenhouse is ideal for higher profit as against open field
3. From an economic point of view, greenhouse technology is preferably ideal for higher tomato productivity and profit.

6.3 Recommendations

1. Farmers should be encouraged to adopt greenhouse technology as it gave higher productivity and economic returns.
2. Further studies should be conducted to validate the findings of the research.

REFERENCES

Abdussamee, H., Hussain, M., Ali, M., Siddique, M. S. and Khan, S. U. (2014). Genetic response of tomato germplasm against early blight and its management through fungicides. *Appl. Sci. Rep*, *2*(3): 119-127.

Abolusoro, P. F. and Abolusoro, S. A. (2017). Evaluation of Different Manures Application on Fruit Quality of Tomato in the Derived Savannah Ecological Zone of Nigeria. *Horticulture International Journal*, *1*(2).

Abraham, J. and Thomas, T. D. (2017). Hairy root culture for the production of useful secondary metabolites. In *Biotechnology and Production of Anti-Cancer Compounds*. New York: Springer, Cham. pp. 201-230.

Adams, S. R. Woodward, G. C. & Valdes, V. M. (2002) The effect of leaf removal and of modifying temperature set-points with solar radiation on tomato. *Endeavour*, *40*(3): 184-190.

Addo, J. K., Osei, M. K., Mochiah, M. B., Bonsu, K. O., Choi, H. S. and Kim, J. G. (2015). Assessment of farmer level postharvest losses along the tomato value chain in three agro-ecological zones of Ghana. *International Journal*, *2*(9): 2311-2476.

Adejuwon, J. O. (2017). An assessment of the changing pattern in tomato cultivation in Sokoto-Rima River Basin, Nigeria. *Applied Tropical Agriculture*, *22*(2): 88-93.

Adepoju, A. O. (2014). Post-harvest losses and welfare of tomato farmers in Ogbomosho, Osun state, Nigeria. *Journal of Stored Products and Postharvest Research*, *5*(2): 8-13.

Aduhene-Chinbuah, J. (2018). *Physiology, Growth, Yield and Fruit Quality of Selected Greenhouse Tomatoes (Solanum Lycopersicum) Varieties as Affected by Different Growing Media and Potting Bag Sizes* (Doctoral dissertation, University of Ghana).

Aggarwal, P., Goyal, P. and Kapoor, S. (2016). Effect of drying methods and pre-treatments on phytonutrients of tomato slices. *International Journal of Food and Fermentation Technology*, *6*(2): 421-432.

Alelign, S. (2020). *Evaluation of the efficacy of Trichoderma and Pseudomonas species against bacterial wilt (Ralstonia isolates) of tomato (Lycopersicum spp.)* (Doctoral dissertation, Addis Ababa University).

Amaefula, C. (2017). *Genetic Improvement Of Fruit Quality And Adaptation Traits Of Exotic Tomato Varieties In A Humid Tropical Environment* (Doctoral dissertation, Kanu State University).

Amartey, J. N. A. (2013). *Estimation of postharvest losses and analysis of insecticide residues in some selected vegetable crops in the Greater Accra Region of Ghana* (Master's dissertation, University of Ghana).

Anderson, T. R., Hawkins, E. and Jones, P. D. (2016). CO_2, the greenhouse effect and global warming: from the pioneering work of Arrhenius and Callendar to today's Earth System Models. *Endeavour*, *40*(3): 178-187.

Andreas, P. (2013). *Smuggler nation: how illicit trade made America*. Oxford University Press.

Aysan, Y. and Horuz, S. (2015). Commercially Important Vegetable Crop Diseases. In *Handbook of Vegetable Preservation and Processing*. Kenya: CRC Press. pp. 158-177.

Bailey, B. J. (2002) Optimal Control of Carbon dioxide enrichment in tomato greenhouse. *Acta Horticulture 578*, 63-70

Bartz, J. A., Sargent, S. A. and Mahovic, M. (2013). Guide to identifying and controlling postharvest tomato diseases in Florida. *IFAS Extension University of Florida, (HS866):* 1-11.

Bergougnoux, V. (2014). The history of tomato: from domestication to biopharming. *Biotechnology advances*, *32*(1): 170-189.

Bethke, J. A., Kabashima, J. N., Newman, J. P., Robb, K. L. and Wilen, C. A. (2014). Insects, mites, and other invertebrate pests. *Container Nursery Production and Business Management Manual*, *3540*, 201.

Bhowmik, D., Kumar, K. S., Paswan, S. and Srivastava, S. (2012). Tomato-a natural medicine and its health benefits. *Journal of Pharmacognosy and Phytochemistry*, *1*(1): 33-43.

Bita, C. and Gerats, T. (2013). Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in plant science*, *4*, 273.

Blanca, J., Cañizares, J., Cordero, L., Pascual, L., Diez, M. J. and Nuez, F. (2012). Variation revealed by SNP genotyping and morphology provides insight into the origin of the tomato. *PloS one*, *7*(10): e48198.

Blanca, J., Montero-Pau, J., Sauvage, C., Bauchet, G., Illa, E., Díez, M. J. & Cañizares, J. (2015). Genomic variation in tomato, from wild ancestors to contemporary breeding accessions. *BMC genomics*, *16*(1): 1-19.

Blok, C., Baumgarten, A., Baas, R., Wever, G. and Lohr, D. (2019). Analytical methods used with soilless substrates. In *Soilless Culture*. Elsevier. pp. 509-564.

Boateng, F. O., Amoah-Mensah, J., Anokye, M., Osei, L. and Dzebre, P. (2017). Modeling of tomato prices in Ashanti region, Ghana, using seasonal autoregressive integrated moving average model. *Journal of Advances in Mathematics and Computer Science*, 1-13.

Borghi, M., Perez de Souza, L., Yoshida, T. and Fernie, A. R. (2019). Flowers and climate change: a metabolic perspective. *New Phytologist*, *224*(4): 1425-1441.

Cao, C. (2012). *Characterization of management and environment effects on cultivated tomatoes* (Doctoral dissertation, The Ohio State University).

Castilla, N. (2013). *Greenhouse technology and management*. Nairobi: CABI.

Chakraborty, I., Chattopadhyay, A. R. U. P., Chakraborty, I. and Chattopadhyay, A. (2018). Pre-and post-harvest losses in vegetables. *Advances in Postharvest Technologies of Vegetable Crops; CRC Press: Boca Raton, FL, USA*, 25-87.

Chaudhary, P., Sharma, A., Singh, B. and Nagpal, A. K. (2018). Bioactivities of phytochemicals present in tomato. *Journal of food science and technology*, *55*(8): 2833-2849.

Chauhan, V., Kärki, T. and Varis, J. (2019). Review of natural fiber-reinforced engineering plastic composites, their applications in the transportation sector and processing techniques. *Journal of Thermoplastic Composite Materials*, 0892705719889095.

Chefetz, R. A. (2015). *Intensive Psychotherapy for Persistent Dissociative Processes: The Fear of Feeling Real (Norton Series on Interpersonal Neurobiology)*. WW Norton & Company.

Chen, Y., Badillo-Vargas, I. E., Martin, K., Rotenberg, D. and Whitfield, A. E. (2019). Characterization of novel thrips vector proteins that bind to tomato spotted wilt virus. *Plant Health 2019.*

Costa, J. M., and Heuvelink, E. (2018). The global tomato industry. *Tomatoes. Boston, USA: CABI*, 1-26.

Creech, C. F., Henry, R. S., Fritz, B. K. and Kruger, G. R. (2015). Influence of herbicide active ingredient, nozzle type, orifice size, spray pressure, and carrier volume rate on spray droplet size characteristics. *Weed technology*, *29*(2): 298-310.

Csizinsky, A. A. (2005) "Production in the open field," in Tomatoes, ed E. Heuvelink (Wallingford, UK: CABI), 237-256.

Deribe, H., Beyene, B. and Beyene, B. (2016). Review on pre and post-harvest management on quality tomato (Lycopersicon esculentum Mill.) production. *Food Science and Quality Management*, *54*, 72-79.

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M. and De Vries, G. (2013). The construction of world input–output tables in the WIOD project. *Economic Systems Research*, *25*(1): 71-98.

Dijkstra, J. and de Jager, C. (2012). *Practical plant virology: protocols and exercises*. Springer Science & Business Media.

DiMarco-Crook, C. and Xiao, H. (2015). Diet-based strategies for cancer chemoprevention: the role of combination regimens using dietary bioactive components. *Annual review of food science and technology*, *6*, 505-526.

Dixon, G. R., Collier, R. H. and Bhattacharya, I. (2014). An assessment of the effects of climate change on horticulture. In *Horticulture: Plants for People and Places, Volume 2* (pp. 817-857). Springer, Dordrecht.

Dreistadt, S. H. (2016). *Pests of landscape trees and shrubs: an integrated pest management guide* (Vol. 3359). UCANR Publications.

Duke, J. A. (2018). *CRC handbook of nuts*. New York: CRC Press.

Eklund, C. R.B. Caetano, L C. S., Shimoyas, F.J.M and Gomes, J. M. R. (2005) Performance of tomato genotypes under protected cultivation. Horticultura Brasileira, 23 (4): 1015-1017

Ercolano, M. R., Sanseverino, W., Carli, P., Ferriello, F. and Frusciante, L. (2012). Genetic and genomic approaches for R-gene mediated disease resistance in tomato: retrospects and prospects. *Plant cell reports*, *31*(6): 973-985.

Estabrook, B. (2012). *Tomatoland: How modern industrial agriculture destroyed our most alluring fruit*. Andrews McMeel Publishing.

Fageria, N. K. and Moreira, A. (2011). The role of mineral nutrition on root growth of crop plants. *Advances in agronomy*, *110*, 251-331.

Gebhardt, C. (2016). The historical role of species from the Solanaceae plant family in genetic research. *Theoretical and Applied Genetics*, *129*(12): 2281-2294.

Gessler, C., Pertot, I. and Perazzoli, M. (2011). *Plasmopara viticola:* a review of knowledge on downy mildew of grapevine and effective disease management. *Phytopathologia Mediterranea*, *50*(1): 3-44.

Ghana Meteorological Agency (2008), Mampong – Ashanti.

Gleason, M. L. and Edmunds, B. A. (2015). *Tomato diseases and disorders*. Iowa State University, University Extension.

Gould, W. A. (2013). *Tomato production, processing and technology*. New York: Elsevier.

Grandillo, S., Chetelat, R., Knapp, S., Spooner, D., Peralta, I., Cammareri, M. & Ercolano, M. R. (2011). Solanum sect. Lycopersicon. In *Wild crop relatives: Genomic and breeding resources*. Berlin, Heidelberg: Springer. pp. 129-215.

Gruda, N., Bisbis, M. and Tanny, J. (2019). Impacts of protected vegetable cultivation on climate change and adaptation strategies for cleaner production–a review. *Journal of Cleaner Production*, *225*, 324-339.

Guodaar, L. (2015). *Effects of climate variability on tomato crop production in the Offinso North District of Ashanti region* (Doctoral dissertation).

Hari, V. (2019). *Plant foods for nutritional good health*. India: Notion Press.

Hatfield, J. L. and Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and climate extremes*, *10*, 4-10.

Howell, C. H. (2010). *Flora mirabilis: how plants have shaped world knowledge, health, wealth, and beauty*. National Geographic Books.

Hyman, C. (2019). *Tomato: A Global History*. Reaktion Books.

Jacobson, M. (2018). *Focus on phytochemical pesticides*. New York: CRC Press.

Jewell, C. P., Zhang, S. V., Gibson, M. J., Tovar-Méndez, A., McClure, B. and Moyle, L. C. (2020). Intraspecific genetic variation underlying postmating reproductive barriers between species in the wild tomato clade (*Solanum* sect. Lycopersicon). *Journal of Heredity*, *111*(2): 216-226.

Keller, M. (2020). *The science of grapevines*. London: Academic Press.

Kelley, W. T., Boyhan, G. E., Harrison, K. A., Sumner, P. E., Langston, D. B., Sparks, A. N. & Fonsah, E. G. (2010). Commercial tomato production handbook.

Khadivi-Khub, A. (2015). Physiological and genetic factors influencing fruit cracking. *Acta Physiologiae Plantarum*, *37*(1): 1718.

Khare, D. and Bhale, M. S. (2016). *Seed technology*. London: Scientific Publishers.

Kirnak, H., Kaya, C., Tas, I. and D. Higgs (2001). The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants, Bulg, Journal of Plant Physiology 27(3/4):34-46

Knapp, S. and Peralta, I. E. (2016). The tomato (*Solanum lycopersicum* L., Solanaceae) and its botanical relatives. In *The tomato genome*. Berlin, Heidelberg: Springer. pp. 7-21.

Kroschel, J., Mujica, N., Okonya, J. and Alyokhin, A. (2020). Insect Pests Affecting Potatoes in Tropical, Subtropical, and Temperate Regions. In *the Potato Crop*. Springer, Cham. pp. 251-306

Kubota, C., De-Gelder, A. and Peet, M.M. (2018) Greenhouse Tomato Production. In Tomatoes: CABI Publishing: Wallingford, UK, pp 276-313, ISBN 9781780641942.

Kumar, K., Paswan, S. and Srivastava, S. (2012). Tomato-a natural Medicine and its health benefits. *Journal of Pharmacognosy and Phytochemistry*, *1*(1).

Kumar, R. A. Vijayalatha, K. R. Alagosan, A and Veeraragavathatham, D. (2007). Performance of certain tomato (Lycopersiconesculentum) genotypes under greenhouse and open conditions in summer. Journal of Ecobiology 19(2) 105-112

Kupperman, K. O. (2012). *The Atlantic in world history*. Oxford University Press.

Lebeda, A., Mieslerová, B., Petřivalský, M., Luhová, L., Špundová, M., Sedlářová, M. & Pink, D. A. (2014). Resistance mechanisms of wild tomato germplasm to infection of Oidium neolycopersici. *European journal of plant pathology*, *138*(3): 569-596.

LeHoullier, C. (2014). *Epic Tomatoes: How to Select and Grow the Best Varieties of All Time*. Storey Publishing.

Liu, X. Y., Jiao, X.Chang, T.T., Guo, S. R. and Xu, Z. G. (2018). Photosynthesis and leaf development of cherry tomato seedlings under different LED- based blue and red photon flux ratios. Photosynthetica, 56, 1-6.

Luo, Y., Pongnak, W. and Soytong, K. (2015). Two edible mushrooms' interaction against fusarium wilt which caused by F. oxysporum f. sp. lycopersici. *Journal of Agricultural Technology*, *11*(2): 539-550.

Manandhar, S., Vogt, D. S., Perret, S. R. and Kazama, F. (2011). Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. *Regional Environmental Change*, *11*(2): 335-348.

Manning, J. (2018). *Field guide to fynbos*. Penguin Random House South Africa.

Marcelis, L F.M., Mans, F. M. and Heuvelink, E. (2002) The latest development in the lighting technologies in Dutch horticulture. Acta Horticulturac 580, 35-42.

Masunga, A. W. (2014). *Assessment of socio-economic and institutional factors influencing tomato productivity amongst smallholder farmers: a case study of Musoma municipality, Tanzania* (Doctoral dissertation, Sokoine University of Agriculture).

McNamee, G. (2017). *Tortillas, Tiswin, and T-Bones: A Food History of the Southwest*. University of New Mexico Press.

Mensah, O. E. (2015). *Comparative studies on growth and yield of pleurotus ostreatus on different types of substrates* (Doctoral dissertation).

Monchiero, M., Gullino, M. L., Pugliese, M., Spadaro, D. and Garibaldi, A. (2015). Efficacy of different chemical and biological products in the control of Pseudomonas syringae pv. actinidiae on kiwifruit. *Australasian Plant Pathology*, *44*(1): 13-23.

Motamedzadegan, A. and Tabarestani, H. S. (2011). Tomato processing, quality, and nutrition. *Handbook of Vegetables and Vegetable Processing*, 739-757.

Mtasa, T., Mangoma, N. and Dhlamini, Z. (2014). Sensitivity of Some Pathogen Isolates to Fungicides Commonly Used in Vegetable Greenhouses in Zimbabwe.

Narayanasamy, P. (2011). Detection of fungal pathogens in plants. In *Microbial Plant Pathogens-Detection and Disease Diagnosis:* (pp. 5-199). Springer, Dordrecht.

Nicola, S. and Pignata, G. (2018). Profitability, marketing, and vegetable loss and waste. *Good agricultural practices for greenhouse vegetable production in the South East European countries: Principles for sustainable intensification of smallholder farms*, *230*.

Nordey, T., Basset-Mens, C., De Bon, H., Martin, T., Déletré, E., Simon, S. & Dubois, T. (2017). Protected cultivation of vegetable crops in sub-Saharan Africa: limits and prospects for smallholders. A review. *Agronomy for sustainable development*, *37*(6): 53.

Ntinas, G. K., Neumair, M., Tsadilas, C. D. and Meyer, J. (2017). Carbon footprint and cumulative energy demand of greenhouse and open-field tomato cultivation systems under Southern and Central European climatic conditions. *Journal of cleaner production*, *142*, 3617-3626.

Oakeley, H., Knowles, J., De Swiet, M. and Dayan, A. (2015). *A Garden of Medicinal Plants*. Hachette: UK.

Odame, P. S. (2009). Manual on Greenhouse Technology. Agricultural Information Resource Centre. Essenstio Co., LTD., Nairobi, Kenya.

O'Shea, N., Arendt, E. K. and Gallagher, E. (2012). Dietary fibre and phytochemical characteristics of fruit and vegetable by-products and their recent applications as novel ingredients in food products. *Innovative Food Science & Emerging Technologies*, *16*, 1-10.

Ozturk, M., Hakeem, K. R., Ashraf, M. and Ahmad, M. S. A. (Eds.). (2019). *Crop production technologies for sustainable use and conservation: physiological and molecular advances*. CRC Press.

Pankaj, R., Gupta, S., Azad, C. and Singh, R. (2020). Diseases of Tomato Crops and Their Management. *Diseases of Fruits and Vegetable Crops: Recent Management Approaches*, 195.

Parrella, G. (2020). Sources of resistance in wild Solanum germplasm (section Lycopersicon) to parietaria mottle virus, an emerging virus in the Mediterranean basin. *Plant Pathology*.

Perveen, R., Suleria, H. A. R., Anjum, F. M., Butt, M. S., Pasha, I. and Ahmad, S. (2015). Tomato (Solanum lycopersicum) carotenoids and lycopenes chemistry; metabolism, absorption, nutrition, and allied health claims—A comprehensive review. *Critical reviews in food science and nutrition*, *55*(7): 919-929.

Poprac, P., Jomova, K., Simunkova, M., Kollar, V., Rhodes, C. J. and Valko, M. (2017). Targeting free radicals in oxidative stress-related human diseases. *Trends in pharmacological sciences*, *38*(7): 592-607.

Porch, T. G., Beaver, J. S., Debouck, D. G., Jackson, S. A., Kelly, J. D. and Dempewolf, H. (2013). Use of wild relatives and closely related species to adapt common bean to climate change. *Agronomy*, *3*(2): 433-461.

Pouliot, A. (2018). *The Allure of Fungi*. CSIRO Publishing.

Racsko, J. and Schrader, L. E. (2012). Sunburn of apple fruit: Historical background, recent advances and future perspectives. *Critical reviews in plant sciences*, *31*(6): 455-504.

Rivière, M., Derr, J. and Douady, S. (2017). Motions of leaves and stems, from growth to potential use. *Physical biology*, *14*(5): 051001.

Robinson, E. J. and Kolavalli, S. L. (2010). *The case of tomato in Ghana: Marketing* (No. 20). International Food Policy Research Institute (IFPRI).

Rosbakh, S., Pacini, E., Nepi, M. and Poschlod, P. (2018). An unexplored side of regeneration niche: seed quantity and quality are determined by the effect of temperature on pollen performance. *Frontiers in plant science*, *9*, 1036.

Ruocco, M., Giorgini, M., Alomar, O., Blum, B., Köhl, J. and Nicot, P. C. (2010). Biocontrol in selected crops. Number 2: Tomato.

Saba, N., Tahir, P. M. and Jawaid, M. (2014). A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. *Polymers*, *6*(8): 2247-2273.

Salim, S. S. (2017). *Influence of Effective Microorganisms Consortium Production and Quality Nutrients of Tomatoes (Lycopersicon esculentum)* (Doctoral dissertation, The State University of Zanzibar (SUZA)).

Savvas, D. and Gruda, N. (2018). Application of soilless culture technologies in the modern greenhouse industry—A review. *Eur. J. Hortic. Sci*, *83*(5): 280-293.

Seid, A., Fininsa, C., Mekete, T., Decraemer, W. and Wesemael, W. M. (2015). Tomato (Solanum lycopersicum) and root-knot nematodes (Meloidogyne spp.)–a century-old battle. *Nematology*, *17*(9): 995-1009.

Shah, V. V., Shah, N. D. and Patrekar, P. V. (2013). Medicinal plants from Solanaceae family. *Research journal of pharmacy and technology*, *6*(2): 143-151.

Shahid, M., Zaidi, A., Khan, M. S., Rizvi, A., Saif, S. and Ahmed, B. (2017). Recent advances in management strategies of vegetable diseases. In *Microbial strategies for vegetable production*. Springer, Cham. pp. 197-226.

Shamshiri, R. R., Jones, J. W., Thorp, K. R., Ahmad, D., Che Man, H. and Taheri, S. (2018). Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: a review. *International agrophysics*, *32*(2).

Shankar, R., Harsha, S. and Bhandary, R. (2014). A practical guide to identification and control of tomato diseases. *Tropica Seeds Pvt. Ltd*.

Singh, A. K., Singh, M. K., Singh, V., Singh, R., Raghuvanshi, T. and Singh, C. (2017). Debilitation in tomato (Solanum lycopersicum L.) as result of heat stress. *Journal of Pharmacognosy and Phytochemistry*, *6*(6): 1917-1922.

Singh, R. S. (2018). *Plant diseases*. London: Oxford and IBH Publishing.

Sinha, K. and Khare, V. (2017). Review on: Antinutritional factors in vegetable crops. *The Pharma Innovation Journal*, *6*(12): 353-358.

Smith, K. M. (2012). *A textbook of plant virus diseases*. New York: Elsevier.

Soto, F., Gallardo, M., Giménez, C., Peña-Fleitas, T. and Thompson, R. B. (2014). Simulation of tomato growth, water and N dynamics using the EU-Rotate_N model in Mediterranean greenhouses with drip irrigation and fertigation. *Agricultural Water Management*, *132*, 46-59.

Sowley, E. N. K. and Damba, Y. (2013). Influence of staking and pruning on growth and yield of tomato in the Guinea Savannah Zone of Ghana. *International J of Scientific & Technology Research*, *2*(12): 103-107.

Srivastava, S., Boyat, S. and Sadistap, S. (2014). A novel vision sensing system for tomato quality detection. *International Journal of Food Science*, *2014*.

Strickler, S. R., Bombarely, A., Munkvold, J. D., York, T., Menda, N., Martin, G. B. and Mueller, L. A. (2015). Comparative genomics and phylogenetic discordance of cultivated tomato and close wild relatives. *PeerJ*, *3*, e793.

Tarter, B. (2020). *Virginians and Their Histories*. University of Virginia Press.

Valderas-Martinez, P., Chiva-Blanch, G., Casas, R., Arranz, S., Martínez-Huélamo, M., Urpi-Sarda, M. and Estruch, R. (2016). Tomato sauce enriched with olive oil exerts greater effects on cardiovascular disease risk factors than raw tomato and tomato sauce: A randomized trial. *Nutrients*, *8*(3): 170.

Vallad, G. E., Messelink, G. J. and Smith, H. A. (2018). Crop protection: Pest and Disease Management. In *Tomatoes* (Vol. 13). New Delhi: CABI. pp. 207-257.

Van Wyk, B. E. and Wink, M. (2018). *Medicinal plants of the world*. CABI.

van Zonneveld, M., Rakha, M., Tan, S. Y., Chou, Y. Y., Chang, C. H., Yen, J. and Solberg, S. Ø. (2019). Understanding patterns of abiotic and biotic stress resilience to unleash the potential of crop wild relatives for climate-smart legume breeding. *bioRxiv*, 596072.

van Zonneveld, M., Rakha, M., yee Tan, S., Chou, Y. Y., Chang, C. H., Yen, J. Y. & Solberg, S. Ø. (2020). Mapping patterns of abiotic and biotic stress resilience uncovers conservation gaps and breeding potential of Vigna wild relatives. *Scientific reports*, *10*(1): 1-11.

Vethavalli, S. and Sudha, S. S. (2012). In vitro and in silico studies on biocontrol agent of bacterial strains against *Fusarium oxysporum* f. sp. lycopersici. *Research in Biotechnology*, *3*(2).

Waheed, K., Nawaz, H., Hanif, M. A. and Rehman, R. (2020). Tomato. In *Medicinal Plants of South Asia*. Elsevier. pp. 631-644

Welbaum, G. E. (2015). *Vegetable production and practices*. Switzerland: CABI.

White, R. E. (2015). *Understanding vineyard soils*. Oxford University Press.

Wills, R. and Golding, J. (2016). *Postharvest: an introduction to the physiology and handling of fruit and vegetables*. UNSW press.

Wright, S. (2020). *Meditations in green*. Oxford: Little Brown Press.

Xu, Z. and Deng, M. (2017). Fabaceae or Leguminosae. In *Identification and Control of Common Weeds: Volume 2* (pp. 547-615). Springer, Dordrecht.

Yan, H., Acquah, S. J., Zhang, C., Wang, G., Huang, S., Zhang, H. and Wu, H. (2019). Energy partitioning of greenhouse cucumber based on the application of Penman-Monteith and Bulk Transfer models. *Agricultural Water Management*, *217*, 201-211.

Zahedi, S. M. and Ansari, N. A. (2012). Comparison in Quantity Characters (Flowering and fruit set) of ten selected tomato (*Solanum lycopersicum* L.) Genotypes under subtropical climate conditions (Ahvaz). *Intl. Res. J. Appl. Basic. Sci*, *3*(6): 1192-1197.

Zhang, Z., Heinemann, P. H., Liu, J., Baugher, T. A. and Schupp, J. R. (2016). The development of mechanical apple harvesting technology: A review. *Transactions of the ASABE*, *59*(5): 1165-1180.

Zhu, Y., Klee, H. J. and Sarnoski, P. J. (2018). Development and characterization of a high-quality plum tomato essence. *Food chemistry*, *267*, 337-343.