Journal of Science and Technology, Special Issue Vol. 1 No 1 (2024), pp 70 - 93

https://dx.doi.org/10.4314/just.v1i1.6s

EFFECTS OF GREENHOUSE TECHNOLOGY ON TOMATO GROWTH AND YIELD (PRODUCTION) IN THE TRANSITIONAL ZONE OF GHANA

Thomas Abindaw[1], David Atiiwin Abugri[2], Kofi Atiah[3]
[1]Department of Land Economy, Faculty of Art and Built environment, KNUST, Kumasi-Ghana
[2]Department of Crop and Soil Sciences Education, Faculty of Agriculture Education, Mampong – Ashanti, University of Education, Winneba
[3]Department of Soil Science, School of Agriculture, University of Cape Coast, Cape Coast, Ghana

Corresponding author: abindaw111@gmail.com

ABSTRACT

Greenhouse technology has been recognised for its potentials in promoting food security, reducing greenhouse gas emissions, efficient water resources management, and improving environmental sustainability globally. Despite the numerous benefits it offers, farmers have still not fully embraced its usage. Little information also exists regarding how adopting the technology can help promote tomato productivity in the midst of climate change and land scarcity. This has not only resulted in vast land degradation but also a persistent importation of tomatoes at exorbitant cost. This study aims to investigate how greenhouse technology can be utilised to promote tomato productivity and eradicate poverty within limited land resources. The experiment was conducted using a randomised complete block design with 45 tomato seedlings planted in each environment and the parameters measured were tomato growth, yield, and value-cost ratio. The results showed that greenhouse technology significantly increased yield of tomatoes, with higher marginal returns than the open field. This indicates that should GT be adopted, limited amount of land could be needed to produce to keep pace with local demand, halt poverty, hunger, and tomato importations. The study concludes that adopting GT has potentials in increasing tomato productivity with limited land size. The technology is an opportunity to help achieve the overarching goal of ending poverty, hunger, and malnutrition. Future study is needed on farmers' adoption ability, sustainability and financial viability of the technology by using revenue and cost streams covering the entire economic life of the greenhouse production system in the transitional zone of Ghana.

Keywords: greenhouse technology, open field, food security, Lycopersicon esculentum, value-cost-ratio (VCR),

INTRODUCTION

Due to the significant impact of agriculture on greenhouse gas emissions and the environment, it is one of the major strategies for mitigating and adapting to climate change. Embracing innovative farming techniques could help us lessen the effects of climate change, protect the environment, and ensure sustainable food productivity. Implementation of sustainable agricultural practises like crop rotation, intercropping, cover crops, and greenhouse technology are a few approaches that enhance ecosystem quality and reduce the need of chemical fertilisers and pesticides that are unhealthy for the environment.

It is widely acknowledged that greenhouse technology has the potentials to improve global environmental sustainability, reduce greenhouse gas emissions, improve water resource management, and bolster food productivity. Due to unproductive marginal areas, land degradation, and urbanisation, it is projected that agricultural land will be reduced to 160.5 million hectares by 2031 (EU Agricultural Markets, 2021). This presents an opportunity to combat hunger, poverty, and malnutrition using greenhouse technology (Adeyeye, 2017). Greenhouse technology improves sustainable agriculture by allowing for all year-round production, enabling cultivation in unfavourable conditions, and minimising environmental impact through the reduction of pesticides, fertilisers, water usage, and soil erosion (Forkuor *et al*. 2022). Studies suggest that growing tomatoes indoors results in higher yields and better quality compared to growing them outdoors (Zarei *et al*., 2019). This is because indoor cultivation provides protection for the crops against various stress factors in a controlled environment (Goudie, 2018; Shamshiri *et al*., 2018). Greenhouse technology (GT) allows for meticulous regulation of environmental variables such as light, temperature, humidity, irrigation, and fertiliser application. This enables the cultivation of specific crops in response to changing climates (Rodrguez *et al*., 2015; Chacha *et al*., 2023). According to the Council for Scientific and Industrial Research (Silva *et al*., 2017), the growth of greenhouse cultivation has the potential to become Ghana the continent's top tomato producer.

Vegetable cultivation plays a crucial role in ensuring food security, nutrition, income generation, and job creation (Fufa *et al*., 2011; Sibomana *et al*., 2016; Zaid *et al*., 2022). Tomato production has been on the rise since 2000, making it a widely consumed food worldwide (Haye *et al*., 2015; Shahbandeh, 2020). Camargo and Camargo (2017) and Melomey *et al*. (2022) have reported that tomatoes are the second most economically important vegetable worldwide, yielding more than 164 million tonnes of fresh fruit from a land area of 4.7 million hectares. Globally, tomato farming has expanded because of greenhouses allowing for year-round production in a range of climates (Naseer *et al*., 2022). With an annual production of 180,766,329 metric tonnes worth US$9.81 billion (https://atlasbig.com), or 47.30 million tonnes worth US$ 50415.26 (Figàs *et al*., 2018; Gruda *et al*., 2018; Xu *et al*., 2019), tomatoes, ranked 319th globally in 2022, are a widely researched greenhouse crop and commercial vegetable.

According to Srinivasan (2010), exports of about 49.50 million tonnes totalled US$ 50802.88 M. According to Aduhene-Chinbuah (2018) and Armah (2022), with 49,459,836 metric tonnes produced, China leads the world with 35% of the total, followed by India, Turkey, USA, and Egypt; this represents 27.4% of the total output, and Ghana comes in 48th position. In total, China sustainably cultivates tomatoes on 1,086,771 hectares, compared to 1,246,524 hectares in four other nations (India, Turkey, USA, and Egypt) (Armah, 2022).

Tomato production supports human food and economic activities (Mirabella *et al*., 2014;

Shahbandeh, 2020) as it continues to be ranked among the most important competitive vegetable crops in terms of income generation both nationally and internationally (Whitfield, 2011; Donkoh *et al*., 2013). Between 2003 and 2012, wholesale prices of tomatoes have more than tripled in real terms (Zant (2018) due to high domestic demand and production gaps, outpacing all other commodities (Mogollón *et al*., 2018). As a result, engaging in commercial production could potentially open doors to greater opportunities, leading to sustainable livelihoods and higher earnings (Holdsworth *et al*., 2020). Moreover, 300,000 people in Ghana's retail and wholesale industries, as well as over 11,728 farmers, are employed in this sector (Armah, 2022). The demand for fresh tomato will continue to rise in many nations throughout the world because of the nutritional value, high mineral content, vitamins, antioxidants, and hormone precursors that it contains (Haye *et al*., 2015; Aduhene-Chinbuah, 2018; Gruda *et al*., 2018; Naseer *et al*., 2022). Tomato-derived phytochemicals and organic acids can treat a variety of illnesses, including type II diabetes, 80% of cardiovascular disorders, neurological diseases, and several types of cancer (Ali *et al*., 2020). Phytochemicals and organic acids derived from tomatoes have the potential to effectively treat a range of illnesses, such as type II diabetes, cardiovascular disorders, neurological diseases, and cancer. Tomato fruit is highly consumed in diets, contributing significantly to human nutrition (Yijo *et al*., 2021). Households consume approximately 440,000 tonnes of diet each year, accounting for 38% to 40% of all vegetable spending (Robert *et al*., 2014; Van Asselt *et al*., 2018).

Tomato is also widely grown in Burkina Faso, Nigeria, and Ghana (Robinson and Kolavalli, 2010). The Upper East, Northern, Brong East, Ahafo, Bono, Ashanti, Eastern, Greater Accra, and Volta regions account for 11,728 of Ghana's total farmers, who produce the majority of the country's tomatoes on a commercial basis for supplies in the market throughout the year (Robinson and Kolavalli, 2010). Tomato production in Ghana is highly seasonal, reflecting differences in access to water and rainfall patterns (Robinson and Kolavalli, 2010). Even though Ghana's tomato production has been rising steadily since 1972, there have been sporadic drops of 0.12% and 0.61% in 2018 and 2021, respectively, which might be contributing to increasing poverty, hunger, and nutritional deficiencies (Laube *et al*., 2012) in the face of rising population (FAO, 2021). The conventional tomato production system, marked by low productivity and excessive vegetative growth, worsened by insufficient storage and processing facilities, result in limited marketing opportunities during the peak harvest period. However, current data shows a trend towards increased tomato production, with large quantity consumed locally (Aduhene-Chinbuah, 2018; Ganiu, 2019). Ghana produced 395,755 tonnes of fresh tomatoes on 92,045 hectares in 2019 compared to a global 180 million tonnes on 5 million hectares (FAOSTA, 2021). According to the Ghana National Tomato Producers' Federation estimates, the country produces about 510,000 metric tonnes of tomatoes annually (Armah, 2022). Aduhene-Chinbuah (2018) and Acqyuaye (2021) also projected that 90 percent of the 300,000 to 318,000 metric tonnes of tomatoes grown by the by the International Food Policy Research Institute (IFPRI) (2020) on an average of 47,000,564 hectares of land in Ghana are consumed locally. Over the past ten years, local tomato consumption has continuously increased, reaching over 450,000 to 800, 000 metric tonnes as at 2013 (MoFA 2020a; FAO 2019). Despite a 2.8% average yearly output growth rate (2009–2019), domestic production has fallen short of consumer demand (MoFA, 2020a; FAO, 2019). This led to a shortage of 132,000 metric tonnes, necessitated the importation of around 75,000–78,000 metric tonnes (Acqaye, 2021) and 27,000 metric tonnes of processed tomatoes from Europe and between 7,000 and 12,000 metric tonnes of tomatoes from Burkina Faso (Armah, 2022).

To bridge the supply-demand gap, Ghana imports about 90% of fresh tomatoes from Burkin Faso, and processed tomatoes, primarily from China (18%) and Italy (36%) which are extremely expensive and out of the reach of majority of the population (Armah, 2022). The Vegetable Producers and Exporters Association of Ghana reported that fresh tomato imported annually from Burkina Faso to bridge the local demand deficit of 800,000 metric tonnes, worth $400 million annually, increased by $99.5 million in 2018. In the off-season, Ghana imports about 70,000–80,000 metric tonnes of fresh tomatoes and 78,000 tonnes of tomato sauce and puree annually from neighbouring countries (Awo, 2012; Aduhene-Chinbuah, 2018). UN Comrade (2019) statistics for the period between 2007 and 2017 indicate that upon government support for the sector in tomato production, a quarter (100,000 tonnes) of local supply observed to be imported (Van Asselt *et al*., 2018) for local consumption.

To locally produce to fill the deficit under the open field will require an additional 9,500 hectares of land but with greenhouse technology, just about 400 hectare-land is needed (Acquaye, 2021; myjoyonline.com). Unfortunately, just about 1.20% (0.564 hectare =160 greenhouses) of the total land used for tomato cultivation is under greenhouse environment with the remaining 98.8% being open-fields (World Bank Group, 2014; Acquaye, 2021).

Despite the benefits tomatoes offer, their production faces several challenges. These challenges include inadequate available land or inadequate supply of suitable land, low market prices, post-harvest losses, and therefore a deficit in meeting local consumption demands (Figàs *et al*., 2018; Xu *et al*., 2019), limited storage facilities, a lack of processing companies to buy and process fresh tomatoes, and an underdeveloped tomato supply chain (Awo, 2012; Verma *et al*., 2015). Economically, whiles there is a large market for red tomatoes in the Atlantic area within the growing season, especially on the wholesale market (Flores and Villalobos, 2018), there is a limited market for fresh green tomatoes, limited processing facility (Chanda *et al*., 2021) and in good growing seasons there are general local market "gluts'' (Chatha & Butt, 2015).

Even though greenhouse technology plays significant roles in tomato production at the global front, its wider acceptability and usage among many vegetable farmers especially tomato growers ranging from peasant to commercial is still limited despite the recent introduction of the technology to boost vegetable production in the country (Forkuor *et al*., 2022). In addition, despite Ghana government's flagship programme of planting for Food and Jobs Policy that aims at boosting food production and creating jobs in the country, little information exists regarding wider attention paid to investment and adoption of greenhouse technology. Hence, majority of tomato farmers still cultivating under the open field involving large tracks of land and excessive water usage. Particularly, the Brong and Ahafo Regions that produce tomato in the wet season and the Upper East Region producing the commodity during the dry season (Aboagye-Nuamah *et al*., 2018), majority of farmers still farm on the open environment.

The commodity is still in short supply despite being produced between southern and northern Ghana throughout the year (Hochman *et al*., 2014). There is a continuous decline in annual production rate of 3.5% (1991-2021), 3% (2001-2021) and 2% (2011-2021) of tomato for raw consumption for fresh market (FAO) and 1.85% (1991-2021), 2.6% (2001-2021) and 0.4% (2011-2021) for processed tomato (FAO) in the midst of increasing demand for fresh tomato tomato. According to EU agricultural outlook for markets report (2021), fresh tomato production is expected to decline by 0.4% annually as a result of a shift to small-sized tomato with high added value but lower volume and a strong drop in winter production in Spain with an expected consumption increase in fresh fruits and vegetable by 2031. Therefore, adopting the greenhouse technology in tomato production is one of the surest ways of keeping pace with global demand. Adopting the technology has the potentials of achieving some of the SDGs such as zero hunger, elimination of poverty, climate action and life on land. Furthermore, it is surprising that, despite the emergence of this technology with the potential to enable them to farm throughout an extended timeframe, many tomato farmers continue to hesitate in its adoption upon grappling with land scarcity, declining fertility, low yields and unreliable seasonal climatic conditions (Melomey *et al*., 2022). Moreover, though, tomato production serves as a major source of income for smallholder tomato producing households (Alhassan and Akudugu, 2020) majority of tomato farmers continually live under poverty, hence, the need for this experiment to demystify the ill perception these farmers have about this innovative and productive technology. Despite clear indications that there is robust market growth, suggesting that tomato production is sustainable in the near future, majority of tomato farmers still doubt the potential of the technology. It is therefore against these backgrounds that the study was initiated to examine the effects of greenhouse technology on tomato production by comparing the yield and growth variables and VCR of tomato produced under greenhouse and open-field environments in Ghana's transitional zone.

MATERIALS AND METHODS

Site: The experiment was carried out at the Multi-Purpose Nursery of the University of Education Winneba, Mampong-Ashanti, which lies at the transitional zone between the forest and northern savanna zones of Ghana and lies at 57.6km north of Kumasi on latitude 07^{o}C 04N and longitude 01^{o}C 024W of the equator and is 457.5m above sea level (Metro Dept., 2008).

Climate: Mampong has a bimodal rainfall pattern with annual mean rainfall between 1094.4mm and 1200mm with monthly mean rainfall of about 91.2mm. The major rainy season starts from March to July whereas the minor rainy season occurs from September to November (Metro Dept., 2008). The mean daily temperature ranges between 30.5o C to 26o C. The experiment commenced on the 23rd July to 18th November, 2019.

Materials: 1) TYTANIUM F1 tomato seeds variety nursed was from Nirit Seeds LTD in Accra; 2) 12L capacity pots perforated with five (5) holes at 2.5 cm (90); 3) White polythene sheet 4) Two (2) 12L capacity plastic voltic bottles improvised as rain gauge in the open field to determine the water difference when it rains.

Experimental Design and Treatment

Land preparation: The land was cleared, weeded and levelled using cutlasses, hoes, pick axe and rake for the nursing of the seeds. In general, it is customary to engage in soil preparation procedures before commencing planting activities. These procedures involve the utilisation of specialised equipment to enhance the overall quality of the soil through the fragmentation of clods and the incorporation of nutrients (Schoonover and Crim, 2015).

Nursery: Each hole was nursed with one seed along the seedbeds at the nursery site of the Multi-Purpose Nursery and by the eighth day after nursing, 95% of the seeds had germinated.

Layout of Experimental Plots: Two experimental lines consisting of forty-five pots in each environment (greenhouse and open field) were studied. Calibration of water drip lines were done in both environments using cut Voltic water bottles of 1L capacity in each environment.

Cocopeat (coconut coir): Coconut husk collected and the fibers were pulled out and dried at clean place. This was made from the pith inside a coconut husk by beating and separated into coconut fiber. A cutter was used to chop the dried fibers into smaller pieces and further grinding into finer powder using a mixer grinder. It was then sieved and the resultant peat washed and soaked in water for salt content to be removed. The peat was then squeezed out of water and dried under direct sunlight for dehydration of moisture content before it was sterilized and mixed with poultry dropping for the cropping. Cocopeat was rehydrated completely before it was used as an organic matter growth medium for propagation.

Pot preparation: A total of ninety (90) 12L capacity containers (pots) bought for this project were each perforated at the bottom with five (5) holes at 2.5 cm wide for aeration and draining of excess water. The cocopeat with pH around 5.5-6.8 was sterilized, mixed with poultry droppings and then together mixed with soil and filled into each pot. Each pot was covered with white polythene sheets, spread over the surface of the soil to prevent entry of soil borne diseases. Pots were chosen because applied water and nutrients are readily available to the plants. Pots or containers restrict root growth, accelerating flowering process, increasing yields of tomato and causing early harvest (Sibomana *et al*., 2013; Cordovez *et al*., 2017).

Transplanting: Each three-week old tomato seedling after germination was transplanted on each experimental pot containing 18kg of soil mixed with sterilized cocopeat and poultry droppings.

Irrigation: Each seedling was immediately watered upon transplant. The plant in each pot was irrigated every morning and evening with a 166ml of water delivered through drip lines for twenty (20) minutes except in rainy days.

Fertilizer Application: Calcium nitrate plus Mono ammonium phosphate mixed and potassium nitrate plus Magnesium sulphate were used as Fertigation chemicals in equal amounts using chemigation technique. The concept of “chemigation” refers to the process of injecting various chemicals, such as nitrogen, phosphorus, or pesticides, into irrigation water, which is subsequently applied to the soil through the irrigation system (Carrow *et al*., 2012). Fertilization ratio used during vegetative and fruiting stages was 4kg of Potassium nitrate to 3.2kg magnesium sulphate per 1000litres of water and 3.2kg of calcium nitrate to 0.75kg of mono ammonium phosphate per 1000litres of water respectively. At each fertilization day, fertilizer was applied in the morning and afternoon during the vegetative growth and morning, afternoon and evening during fruiting stage for every 20 munites each time.

Weed control: Weeds were manually controlled using cutlasses, hoes, hand-picking and in some cases herbicides throughout the project’s period. Weeds within pots were controlled by hand picking and the weeds around surrounding environment were controlled using cutlasses, hoes, and in some cases herbicides.

Pests and disease control: Pests (caterpillar, flea beetles, tomato fruit worm etc) and diseases (Leaf blight, Septoria Leaf Spot, Anthracnose, Leaf curl, just to mention a few) found were controlled using Chemaprid 88EC (20ml/8 litres of water) and D-Lion® Fungi 2020 (Copper hydroxide 77% WP) during the project's period.

Data Collection and analysis

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.

Table 1: Data collection of variables and collection procedures

Variable	Data collection procedure
Plant Height	The plant height of each experimental environment was taken weekly for five times using a meter rule to measure from the base of the stem to the apical leaf. The average mean height of experimental plants in each environment was taken.
Number of Branches	Counting of the number of branches of each plant was on weekly basis.
Stem Girth	Stem girth was measured with a vernier caliper and recorded for the experimental tomato plants from 5cm ground level for five times during the vegetative period.
Number of Flowers	Counting of the number of flowers of each experimental tomato plants was done at 10-days intervals.
Fruit Harvesting	The first harvesting was done on the 10th of November, 2019 by hand picking and was followed by subsequent harvesting for two times (at every seven (7) days interval).
Number of Fruits	The total number of fruits harvested from each tomato plant in each pot in each environment was counted and averages determined.
Vertical Fruit Length	The length of all fresh fruits harvested from each environment was measured with a vernier caliper and the averages of the fresh fruit for each environment determined.
Fruit weight	The weight of each experimental fruit in each environment was taken using a weighing scale. The average mean weight of each experimental fruit of each environment was taken with respect to the environment.
Vertical Fruit diameter	The diameter of each experimental fruit on each environment was taken using the Vernier caliper. The average diameter of each experimental fruit on each environment was taken with respect to the environments. This was done every week

Analysis of Data: The data gathered were organized in Microsoft excel 2013 and exported to Minitab version 19.1 for descriptive statistics (means and Std. dev.) and t-test analysis of parameters. Means were separated using the least significant difference (LSD) test in post-hoc analysis with significant differences between means pegged at 5%. However, value cost ratio (VCR) and gross profit, gross profit margin were analysed using the following equations and plotted in bar charts with Microsoft Excel 2013.

The fixed costs associated with basic tools like hoes, cutlasses, water sources among others were held constant and could be disregarded when determining the gross marginal profitability of small-scale productions (Olukosi and Erhabor, 2008). In addition, due to the absence of information on the cost of greenhouse technology and irrigation systems that were already in place at the experimental site and no money was paid for the use of such facilities, the gross profitability margin of tomato production was limited to only variable costs associated with production, and streams of revenues generated. The gross margin was calculated by subtracting the total variable cost (TVC) from the gross revenue. This planning tool was useful in this particular research since the fixed capital known to authors constitutes a small proportion of the experiment. This in line with Eraboh (2005) suggestion that the tool would be appropriate as in the case of small-scale subsistence agriculture. The value cost ratio (VCR) was used to evaluate the overall profitability of using greenhouse technology compared to the open environment (Sommer *et al*., 2013). The Gross Margin Ratio, also referred to as the gross profit margin ratio, is a profitability metric that measures the gross margin of a business in relation to its revenue. It demonstrates the gross profit generated by a business after deducting its Cost of Goods Sold (COGS). The ratio represents the proportion of each Ghana cedi of revenue that the enterprise keeps as gross profit (https://corporatefinanceinstitute.com/resources/knowledge/finance/gross-margin-ratio/).

The VCR is obtained by dividing the value of the marginal product (revenue) by the total variable costs of production (Sommer *et al*., 2013). The value cost ratio (VCR) was employed to assess the gross profitability of greenhouse technology use relative to the open environment (Sommer *et al*., 2013). The value cost ratio was determined by dividing the gross revenues by the total variable cost. The VCR, or Value-to-Cost Ratio, is an essential measure for evaluating business safety (Olorukooba, 2020).

$$VCR = \frac{Total\ revenue}{Total\ variable\ costs} \text{ or TR: TVC} \quad \text{.......eqn 1}$$

Where VCR = value cost ratio, TR = Total gross revenue and TVC = total variable cost.

$$GM = TR - TVC \quad \text{.......eqn 2}$$

Where GM = gross margin, TR = total revenue and Total variable cost.

$$GPM = \frac{Total\ revenue - Total\ variable\ cost}{Total\ Revenue} * 100\% \quad \text{.......eqn 3}$$

Where GPM = gross profit margin, TR = total revenue and Total variable cost.

RESULTS AND DISCUSSIONS

This section covers results and discussions of the height, number of branches, stem girth, number of flowers, number of tomato fruits harvested, vertical fruit length, and vertical fruit diameter of the tomato production under open field and greenhouse environment. It also includes analysis of value cost ratio, gross margin and percentage of gross margin of tomato yields produced from each environment.

Plant height

Figure 1 shows the heights of tomato plants measured every two weeks (1st, 3rd, 5th, 7th, and 9th week) for five times during the vegetative phase after transplanting in the greenhouse and in open field.

The t-test results revealed that there were no significant differences in the mean height of tomato grown between greenhouse and open field except in the first week where the height of tomato in the open field was significantly ($P<0.001$) higher than the greenhouse technology (Table 2a). The slightly higher plant height observed in the open environment could be attributed to the difference in temperature, water and light. Higher average daily temperature of the open field promoted higher production of plant growth hormones, making the plants to grow a bit faster as compared to tomato plants grown under greenhouse technology. This corroborates the findings of Chacha *et al*. (2023) who attributed lower growth of tomato planted in northern slot to the presence of trees that provided shade in the northern side slots, hiding the availability of strong sunlight. The finding is similar to the findings of Pires (2011) and Allen (2015) who observed that plants grown in open field were taller compared to those grown in greenhouses during their investigation on the impact of greenhouse models on growth and yield of tomato. However, the results of this study disagree with the findings of Yeshiwas *et al*. (2016) and Anyega *et al*. (2021) who observed taller height among tomato plants grown in the greenhouse as compared to tomato plants grown in the open field conditions. The differences in plant height observed in this study, which is similar to other studies, could be attributed to difference in geographical locations of the various studies and prevailing environmental conditions. It is obvious that when the plant grows tall, it may produce more flowers, which will proportionally produce corresponding number of fruits, hence, possible higher economic gains.

Branches of tomato

Tomato plants grown in the open field consistently produced many numbers of branches as compared to those grown in the greenhouse over the study period (Figure 2 and Table 2b). Results from the study revealed that the mean number of branches of tomato grown in the open field was consistently significantly ($P<0.05$) higher than those grown in the greenhouse environment (Table 3).

The increase in the number of branches of tomato plants cultivated in the open field as compared to the greenhouse technology observed is akin to Paucek *et al*. (2020) and Angmo *et al*. (2021) who observed higher number of tomatoes branches in the open field as compared to tomatoes grown in the greenhouse technology and this could be attributed to tomato plants' exposure to varied daily temperatures between the two fields. On the other hand, the results of the study contradict with the findings of Kenwar (2011) and Meena *et al*. (2015) who reported higher number of branches among tomato plants grown in the greenhouse as compared to the open field conditions. The variations in the number of branches observed in this study could be attributed to the prevailing environmental conditions as well as the nutrients in the soil. By implication, the branches bear the fruits so it can be expected that tomato in the open field with many branches would bear many fruits.

Stem girth

The tomato stem girth for both environments are presented in Figure 3 and Table 3a. The results showed that the mean stem girth of tomato recorded for the greenhouse technology was significantly ($P<0.05$) lower for 1st, 3rd and 5th week as compared to the open field. However, for the 7th and 9th weeks, a slight difference in the mean stem girths observed were statistically insignificant between both environments (Table 3a).

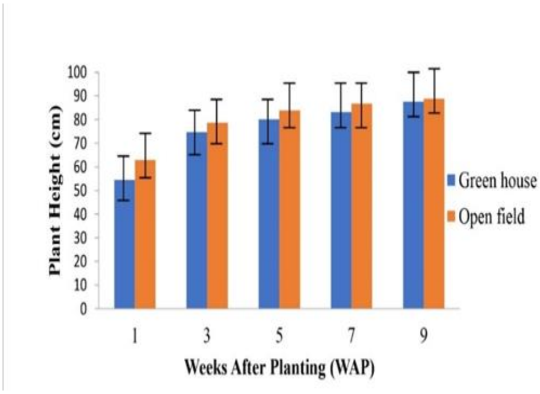

Figure 1: Height of tomato in weeks

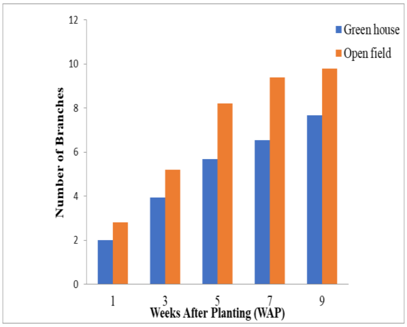

Figure 2: Branches of tomato in each week

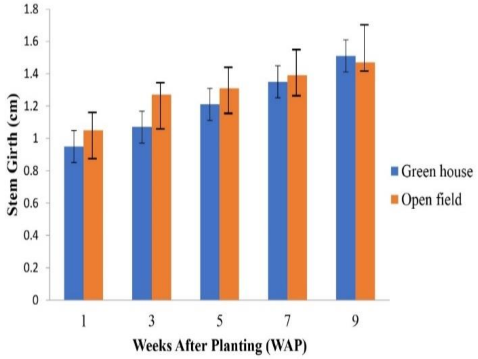

Figure 3: Stem girth of tomato recorded in each week

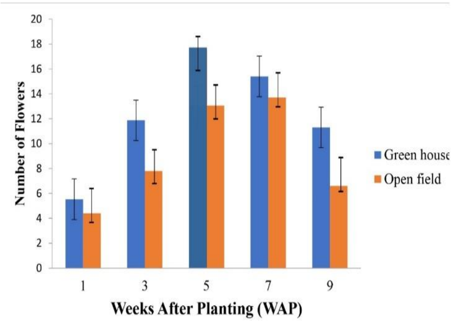

Figure 4: Number of flowers recorded in weeks

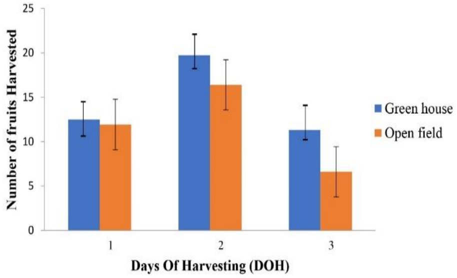

Figure 5: Number of Fruits harvested per week

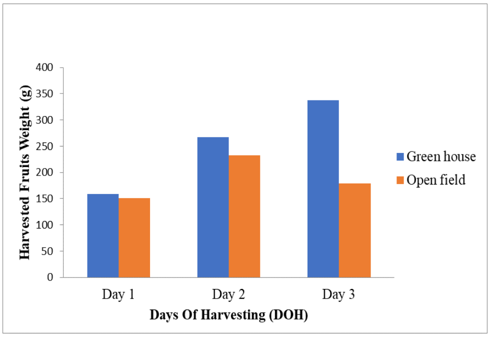

Figure 6: Weight of tomato fruit per week

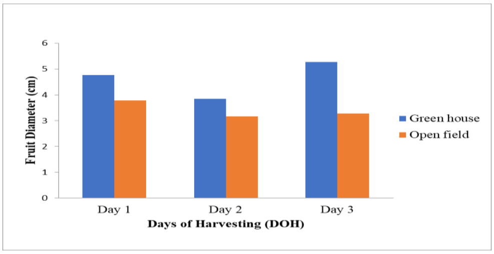

Figure 7: Fruit diameter

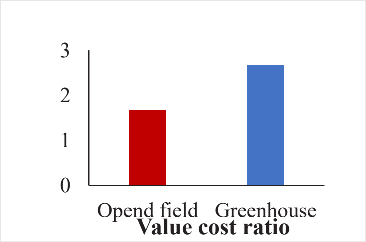

Figure 8: Value cost ratio

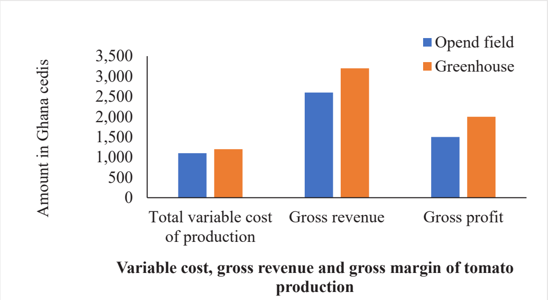

Figure 9: Total variable cost of production, gross revenue and gross margin in tomato production per h

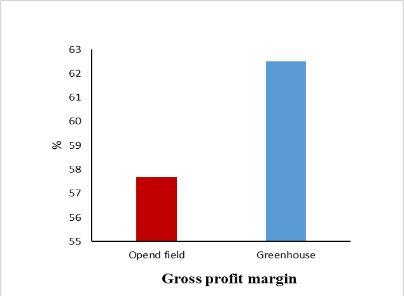

Figure 10: Gross profit margin

Table 2: Tomato height and number of branches recorded under greenhouse and open field environments

	a. Plant heigh (cm)					b. Number of branches				
Treatments/ Weeks	**1 Week**	**3 Weeks**	**5 Weeks**	**7 Weeks**	**9 Weeks**	**1 Week**	**3 Weeks**	**5 Weeks**	**7 Weeks**	**9 Weeks**
Green house	54.38	74.7	80.1	83.2	87.5	2.00	3.93	5.67	6.53	7.67
Open field	62.91	78.6	83.8	86.8	88.8	2.80	5.20	8.20	9.40	9.80
Grand mean	58.64	76.7	81.9	85.0	88.1	2.40	4.57	6.93	7.97	8.73
L.S.D	3.889	4.38	5.84	6.78	6.42	0.456	1.089	0.997	1.089	1.230
C.V	8.9	7.6	9.5	10.7	9.7	25.4	31.9	19.2	18.3	18.8
P-value	<.001	0.079	0.209	0.283	0.695	0.001	0.024	<.001	<.001	0.001

Table 3: stem girth and number of flowers of tomato under greenhouse and open field

	a. Stem girth (cm)					b. Number of flowers				
Treatments/ Weeks	**1 Week**	**3 Weeks**	**5 Weeks**	**7 Weeks**	**9 Weeks**	**1 Week**	**3 Weeks**	**5 Weeks**	**7 Weeks**	**9 Weeks**
Green house	0.95	1.07	1.21	1.35	1.51	5.53	11.87	17.53	15.40	11.30
Open field	1.05	1.27	1.31	1.39	1.47	4.40	7.80	13.00	13.70	6.60
Grand mean	0.99	1.17	1.26	1.37	1.49	4.97	9.83	15.27	14.60	8.90
L.S.D	0.08	0.16	0.07	0.08	0.08	1.924	2.306	4.052	4.54	4.69
C.V	10.60	18.50	7.2	7.40	7.20	51.8	31.40	35.50	41.60	70.20
P-value	0.015	0.018	0.006	0.288	0.399	0.238	0.021	0.003	0.121	0.001

Table 4: number of tomato fruits harvested under greenhouse and open field

	a.**Number of fruits harvested**			b.**Number of fruits harvested weight (g)**		
Treatments/ Weeks	**1st Week**	**2nd Week**	**3rd Week**	**Week 1**	**Week 2**	**Week 3**
Green house	13	27	16	150.47	270.40	300.5
Open field	12	20	11	140.93	220.73	170.8
Grand mean	**13**	**23**	**14**	**145.70**	**245.57**	**235.65**
L.S.D	1.962	3.014	5.79	1.962	3.014	5.79
C.V	21.5	22.3	40.5	21.5	22.3	40.5
P-value	0.582	0.001	<.031	0.582	0.031	<.001

The results suggest that the uncontrolled temperatures and sunlight probably influenced the higher stem girths generally observed among tomato plants grown in the open field (Bhattarai *et al*., 2021). This could be explained that as temperature in the open field increases, photosynthesis, transpiration and respiration increases resulting in rapid stem development as reported by Teskey *et al*. (2015). The finding is in conformity with Paucek *et al*. (2020) who equally observed open field conditions promoting higher stem girth development of tomatoes plants relative to those under controlled (greenhouse technology) environment. This made the plant difficult to log and therefore, produce clean and attractive fruits to satisfy consumer preference hence more capital returns.

Number of flowers

Figure 4 and Table 3b present the number of flowers produced by tomato plants cultivated in both fields with higher number of flowers consistently being produced in the greenhouse condition. Tomato plants grown under greenhouse technology recorded higher of number of flowers than the open field over the entire study period (Figure 4 and Table 3b). Results from the study showed that the

significantly ($P<0.05$) higher mean number of flowers counted in the greenhouse over the open field could be attributed to the limited exposure of such tomato plants to harsh environmental conditions.

The higher mean number of flowers produced in the greenhouse could be explained that, tomato as a warm season crop requires temperature of about 24oC to produce more flowers and this was observed in the greenhouse. Higher temperatures were recorded in the open field while temperatures in the greenhouse were relatively low across the study period. The fewer number of flowers counted in the open field relative to the greenhouse is in line with Mathieu *et al*. (2020) observation that high temperatures in open fields induce flowering abortion, mainly caused by the inhibition of capitulum development between inflorescence meristem formation and the growth of florets. Arnao and Hernández-Ruiz (2020) found that during flowering stage of tomato, high temperatures delay the process of flower initiation. The findings of Ezzaeri *et al*. (2018) and Ro (2021) who investigated the impact of greenhouse models on tomato production found that plants grown in the greenhouse produced higher number of flowers compared with tomato plants grown in the open field, hence, exonerating the findings of the current study. However, the results contradicted the findings of Yeshiwas *et al*. (2016) who reported higher number of flowers among tomato plants grown in the open field compared with tomato plants grown under the greenhouse technology. It is therefore reasoned that, flowering tomato within greenhouse is less susceptible to environmental hazards, hence the recorded higher number of flowers.

Number of fruits

The number of tomato fruits harvested weekly for three consecutive weeks in open field were fewer than in the greenhouse technology (Figure 5 and Table 4a). Even though the results from the study showed that the mean number of fruits harvested from the greenhouse technology were generally higher across the three weeks of harvesting, a significant ($P<0.05$) variation was only observed for the 2nd and 3rd week (Table 4a). With respect to the greenhouse, the number of fruits harvested in each week continually increased magnificently but in the open field, after the second week of harvest, there was a significant decline in the mean number of tomatoes harvested (Table 4a). Significantly, the number of flowers formed on each plant, determined the number of fruits produced. Literally, the more the number of flowers, the more the number of fruits produced, hence, the better the harvest, and the more profitable it turns out to the farmer. The greater number of fruits harvested in the greenhouse technology could be attributed to the greater number of flowers produced finally developed into fruits due to the favorable environmental conditions(Chacha *et al*., 2023). The outcome of the study confirmed the findings of Rana *et al*. (2014) and Ullah *et al*. (2021) who reported higher number of fruits among tomato plants grown under greenhouse environments as compared to the open field. This implies that farmers stand better chance of making good profit when the harvest is good. Contrarily, Angmo *et al*. (2021) reported poor yield in tomato under greenhouse as compared to open field crop because of higher temperature during growth, flowering and fruiting period in the green house.

Fruit weight

Figure 6 and Table 4b show the variations of harvested fruit weight of tomato cultivated in the open field and greenhouse environment. Generally, the results presents that the weights of harvested tomato from the greenhouse are heavier than that of the open field. However, further analysis of the mean differences revealed that it was only in the 2nd and the 3rd weeks that the means weights of harvested tomato fruits in the greenhouse were significantly ($P<0.05$) higher compared to the lower weights recorded in the open environment (Table 4b).

Fruit weight is a very complex trait which is influenced by several weight components, playing a significant role when recommending a suitable cultivar. The differences in fruit weight among tomato plants grown under the greenhouse technology could be attributed to favourable environmental conditions inside the greenhouse as compared to the open field (Chacha *et al*., 2023). This could be explained that, tomato require sub-optimal air temperature during the vegetative growth stage and this influence the plants to produce larger cells to store more starch, leading to higher production of fruits with higher weight as reported by He *et al*. (2019). The results also agreed with the findings of Tringovska *et al*. (2015) and Chacha *et al*. (2023:4) who reported that yield per plant, yield per ha and harvested fruits weight per plant were higher among tomato plants grown under greenhouse conditions. Previous works reported higher weight of harvested fruits per plant among tomato plants grown under greenhouse conditions compared to lower weights among tomato plants grown in the open field (Çolpan *et al*., 2013; Ro *et al*., 2021; Chacha *et al*., 2023), hence, the similar superior weight of tomato generally observed in greenhouse cultivation under the current study. Chakraborty and Sethi (2015) and Akrami (2020) observed similar trends for yield weights of tomato plants grown in greenhouses with respect to open field conditions. However, results of the study refuted the findings of Paucek *et al*. (2020) who found that harvested fruit weight was higher among tomatoes plants grown in the open field as compared with tomatoes plants grown under the greenhouse technology.

Table 5: Vertical fruit length and Diameter of tomato under greenhouse and open

	a. Vertical fruit length (cm)			b. Vertical fruit diameter (cm)		
Treatments/ Weeks	1st Week	2nd Week	3rd Week	1 Week	2 Weeks	3 Weeks
Green house	7.37	6.17	6.20	4.77	3.84	5.27
Open field	6.51	3.10	4.62	3.78	3.17	3.27
Grand mean	6.94	4.64	5.41	4.28	3.50	4.27
L.S.D	1.101	0.852	1.189	1.055	0.749	0.849
C.V	21.2	24.6	29.4	33.0	28.6	26.6
P-value	0.120	<.001	0.011	0.065	0.084	<.001

vertical length of tomato fruit

Table 5a shows the vertical fruit length of harvested tomato fruits cultivated in both greenhouse technology and open environment. The results revealed that with the exception of the first harvest, the vertical length of the tomato fruits harvested from the greenhouse technology were significantly (P<0.05) longer than that in the open field for the 2nd and 3rd harvests. However, the mean vertical length difference between the tomato fruits in greenhouse technology and open environment were insignificant. The result of the current study is similar to the findings of Babu *et al*. (2020) and Waiba *et al*. (2021) who reported that vertical fruit length was longer among tomatoes plant grown under the greenhouse technology as compared to the open field.

vertical fruit diameter

Shown in Figure 7 and Table 5b represent the matured vertical fruit diameter of tomato produced in both environments, where greenhouse technology though consistently recorded longer diameters, a significant (P<0.05) difference was only observed in the last fruits harvested (Table 5b). The results revealed that for the 1st, 2nd and 3rd weeks of harvesting, tomato plants grown under the greenhouse technology had longer diameters compared with those grown in the open field. Findings of the study agreed with the findings of Babu *et al*. (2020) who reported that vertical fruit diameter was longer (6.55 cm) among tomatoes plants grown under the greenhouse technology as compared to the open field (5.49 cm). Randhe *et al*. (2015) also reported higher mean vertical fruit diameter of 6.17 cm among tomato plants grown under the greenhouse technology as compared to vertical fruit length of 5.38 cm among tomato plants grown in the open field. All these values were higher than those found in the present study with the possible reason being the season of cultivation, different environmental conditions and the geographical location of the studies.

Value cost ratio (VCR), of gross profit margin and total variable cost, gross revenue and gross profit estimations

Results from the study shown in Figures; 8 (value cost ratio), 9 (total variable cost, gross revenue and gross profit) and 10 (gross margin profit) are associated with tomato production under the greenhouse technology and the open field. Even though the total variable cost involved in greenhouse production was relatively higher, a positive higher revenue and gross profit margin were realized as compared to the open environment (Figure 9). The results showed a VCR of 2.37 (26:11) for open environment and 2.67 (8:3) for greenhouse environment (Figure 8). The VCR of 26:11 (2.37) means that for every GH₵11.00 spent in producing tomato in the opened environment will generate a corresponding revenue of GH₵26.00 or for every GH₵1.00 spent as costs of production will generate a revenue of GH₵2.37. On the other hand, for every GH₵1.00 spent in tomato production in the greenhouse, will yield an additional revenue amounting to GH₵2.67. However, the greenhouse production was marginally profitable since it recorded a higher VCR of 2.67 with gross profit margin of 62.5% compared to tomato plants cultivated in the open field (VCR = 2.36) with gross profit margin of 57.69 % (Figure 10). The gross profit margin expressed in percentage revealed that greenhouse technology produced about 4.98 % higher than the opened field (Figure 10). The result also means that if tomato is grown in opened environment within the experimental site, the gross profitability margin will decrease by 4.98 %. This showed that more profit was made from the greenhouse production compared to the opened field. Therefore, greenhouse environments help to increase tomato productivity thereby leading to increased revenue, corroborating the findings of Olorukooba (2020). Irrespective of the environment, the value cost ratios were relatively higher than the economic threshold of 2 (Bashagaluke *et al*., 2020). According to Sheahan et al. (2013), a threshold of 2 helps to account for unmeasured costs associated with fertilizer use and the risks and uncertainties in crop farming. In addition, the VCR values obtained for tomato produced in both environments in this study were relatively higher than the VCR values of 1.81 (Audu, Saliu and, Ukwuteno, 2008), 1.80 with GPM of 45% (Madu and Aniobi, 2018), 1.88 with GPM of 46.93%, (Oyewole, Akinbola and Ayanrinde,2018), 2.42 (Olorukooba, 2020), 1.93 – 2.44 (Ali et.al., 2006) and 1.81 – 2.23 (Toungos, 2018). The result implied that in term of choosing a better alternative to opened field approach using the VCR, GM or GPM, greenhouse technology performed better. This is attributed to the higher marketable fruits harvested from the greenhouse technology.

The VCR was employed to assess the gross profitability of using greenhouse technology relative to the open environment (Sommer *et al*., 2013). The study also adopted a measure of gross margin of tomato production by computing the differences between estimated revenue, and total variable cost as applied by Olorukooba (2020) in their work. Comparison of the two environments clearly showed that in term of tomato production using the VCR values, greenhouse technology with value 2.67 is higher than that of 2.37 for opened field. It showed that more gross margin is obtained using greenhouse technology for tomato production than the opened field. The ranking of gross profitability margin of tomato production under the two environments based on the VCR, GM and GPM followed the order: greenhouse technology > open field (Figures 8, 9 and 10). However, the slightest higher cost incurred for the greenhouse technology was attributed to an additional cost associated to the maintenance of the greenhouse. Hence, less amount of money was spent on the open field. The substantial variations observed in the revenue and the gross margins between the greenhouse technology and the opened field could be attributed to higher marketable prices for higher fruits quality harvested in the greenhouse technology. Results of the study confirmed the findings of Castillo *et al*. (2021)

who reported higher significant differences for revenue and profit margins among tomato plants grown under greenhouse conditions as compared to the open field.

Mutisya *et al*. (2016) and Chacha *et al*. (2023) reported that harvested fruits weight per plant were higher among tomato plants grown under greenhouse conditions which resulted in higher economic returns and lowest among tomato plants grown in the open field. This could be explained that tomato plants cultivated under the greenhouse technology produces quality tomato due to favourable environmental conditions, commanding higher prices as compared to tomato plants cultivated in the open field which were susceptible to attack by pests and diseases.

Again, comparing the VCR, and gross profit margin of the present study were higher as when compared to Madu and Aniobi whose results showed a VRC of $1.80, gm=281.56 and gross profit margin equivalent to 45%. This buttresses the fact that, the observed VRC, and GM of the study clearly indicates that the likelihood of farmers making more profit should they adopt greenhouse technology production is very certain.

CONCLUSIONS

The study's objective to assess the potential of greenhouse technology on tomato productivity in terms of the gross margin values revealed that the technology is more profitable. On the basis of that the following conclusions were drawn: the greenhouse technology produced more quality fruits (weight and size) of tomatoes as compared to the open field and from economic point of view, greenhouse technology is preferably ideal for higher tomato productivity and profit. The study revealed that greenhouse tomato cultivation resulted in significantly higher gross margin values (Gh₵60.47) in comparison to direct production (Gh₵1.67). Greenhouse tomato cultivation exhibited superior performance in terms of higher average gross margin values and benefit-cost ratio compared to open field cultivation. The uncontrolled environmental factors limit higher yield and quality of tomatoes in open fields, while greenhouse-grown tomatoes produce better outcomes (Chacha *et al*., 2023). In general, the technology made the controlled environment possible and demonstrated its significance for achieving the best yield and quality of tomato production in Ghana (Chacha *et al*., 2023). Based on VCR values, it could be concluded that tomato production in general was profitable. In addition, based on the conclusions drawn by Adzawla *et al*. (2024) that Fertilizer use was economically viable for farmers who recorded VCR of 2 or higher, tomato production is marginally viable and therefore could be considered a business that is safe to invest with higher margins being generated from the greenhouse technology. Furthermore, Adzawla *et al*. (2024) before drawing such conclusion classified the farmers into two groups where average VCR of at least 2 was economically viable otherwise economically unviable if the average VCR was less than 2. The study concluded that growing tomatoes in a controlled environment was more effective approach for achieving a high gross profit margin than opened field in the transitional zone of Ghana. Hence, switching from the open field production to greenhouse technology is not only marginally profitable (viable) but provides the population with quality fruits for human consumption. Going by greenhouse technology production of tomato will also potentially play a significant role in sustainable land and water management (utilisation), promotes environmental friendliness (less environmental pollution), poverty eradication and sustainable agriculture (promotes food security). So, based on the results of the study, the following recommendations have been made: 1) Farmers who have the financial capability could adopt greenhouse technology, since it has the potentials of giving them higher productivity and marginal returns. 2) Wider public awareness on the economic and productive potentials of the technology is very imperative especially in the midst of shrinking lands for agricultural activities. 3) Government and other stakeholders should invest by expanding the construction of greenhouses especially in the production regions to help increase production as well as promote land utilisation. 4) Future research should look at the financial viability of greenhouse technology by using revenue and cost streams covering the entire economic life of the greenhouse production system in the transitional zone of Ghana.

ACKNOWLEDGMENTS

We express our sincere gratitude to Mr. Emmanuel Kwasi Asiedu for his invaluable review, comments, and constructive recommendations, which greatly contributed to the successful culmination of this manuscript.

DECLARATION OF CONFLICT OF INTEREST

Authors have no any form of conflict of interest.

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