



Evaluation of Agronomic Performances and Fruit Quality of Improved Tomato (*Solanum lycopersicum* L.) lines under greenhouse conditions

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ABSTRACT

Although agriculture is the driving force of Ghana's economy, accounting for one third of GDP and employing more than half of the workforce, Ghana is still far from achieving food security due to serious challenges facing the sector. If agriculture is to fulfill its promise of achieving food and nutrition security in Ghana by 2030, it must take drastic steps towards enhancing vegetable crop production. Greenhouse technology is fast gaining recognition in urban and peri-urban areas. Low tomato production in Ghana is a problem owing to the lack of improved and high-yielding varieties. Evaluation of improved lines of tomato under greenhouse condition which is a fast-growing technology in Ghana can help identify adaptable and promising lines for cultivation. This can lead to increased tomato production as well as meeting consumer demands. In this study, 12 improved lines and 2 local checks of tomato were evaluated under greenhouse conditions to determine their agronomic performances, and fruit quality traits using a Randomized Complete Block Design (RCBD) with three replications. The results indicate that Lines J138 and B24 recorded the highest yields (20.05 t/ha and 23.03 t/ha respectively) while the check varieties, Anna F1 and Nkansah HT gave yields of 18.77 t/ha and 16.96 t/ha, respectively. Lines B24, B25, J138, B45 and B46 also exhibited good fruit quality traits such as pH, pericarp thickness, fruit firmness and shelf life. These promising lines of tomato could be useful germplasm in tomato breeding programmes in Ghana and for cultivation under greenhouse conditions.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the nutritious vegetable crops that is widely cultivated in the world. It is fortified with minerals, vitamins, essential amino acids, sugars and serves as a good source of dietary fiber [1]. Tomato is also high in lycopene, an antioxidant that protects the body from cancer, cardiovascular diseases liver diseases, and boosts the body immune system [2].

In Ghana, tomato contributes significantly to the improvement of livelihoods [3] and it is also an essential component in most food preparations [4]. Domestic production of tomatoes has not kept up with demand, despite expanding from 318,000 tonnes in 2009 to about 420,000 tonnes in 2019 [5,6,7] with an average yield ranging from 8.1 to 8.6 tonnes per hectare [3]. To meet the high domestic demands, there is high importation of fresh tomato estimated at 100,000 tonnes annually [7]. Thus, fresh tomato imports account for about 30% of household consumption, and they are in high demand due to their appealing fruit

quality [8]. Apart from fresh tomato, over 92,000 tonnes of tomato paste [9] and large quantities of other forms of processed tomato products are imported from USA, Spain, Italy, Portugal and China [10]. According to the International Food Policy Research Institute (IFPRI) [6], an additional 736,000 tonnes of fresh tomato would be required to meet both household consumption and industrial demand, if Ghana were to set an intermediate goal of reducing tomato importation.

The low tomato production in Ghana is attributed to major constraints such as high post-harvest losses, biotic (pest and disease) and abiotic (heat stress and low soil fertility) stresses due to climate change. In addition, limited availability of high yielding tomato varieties with excellent fruit quality is one of the major causes of low production [8]. Most of the commercially grown tomato cultivars in Ghana have poor colour and shelf life as well as watery fruits, thereby making them unsuitable for local and export markets [8]. If Ghana's economy is to continue to rely on agriculture for one-third of GDP and to meet its promise of achieving food and nutrition security by 2030 [11], it must

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take drastic measures to increase vegetable crop production.

One way of addressing these challenges is the adoption of greenhouse cultivation system which offers an alternative approach at ensuring sustainable food and nutrition security [12]. Greenhouse crop production has recently increased significantly in Ghana, as it ensures more efficient water and fertilizer use, as well as a better way to control pests and environmental stressors for optimal plant growth resulting in increase in productivity per unit area. Furthermore, greenhouse farming improves crop quality and productivity, resulting in higher economic returns [13].

Although greenhouse cultivation systems prove to be promising, selecting adaptable and high-yielding tomato varieties is an important factor to consider. There is however a limitation on the availability of high-yielding tomato varieties which are adaptable to local climatic conditions for greenhouse cultivation [14]. Furthermore, very little research has been carried out on identifying promising tomato varieties with improved agronomic characteristics, yield, and fruit quality traits for tomato greenhouse cultivation [15]. The aim of this study was to evaluate improved exotic tomato varieties in the greenhouse for their adaptability, yield, and fruit quality.

2. Materials and methods

2.1. Description of study area

This study was carried out at the University of Ghana Forest and Horticultural Crops Research Centre (FOHCREC) which is located at Okumaning-Kade in the Eastern region of Ghana (6° 05' N; 0° 05' W) [16]. The rainfall pattern is bi-modal with peaks (150 and 200 mm) in May/June and September/October [17,18]. The average ambient temperature of the experimental site was 25.1 °C–33.1 °C and relative humidity of 65–79% from September 2019 to January 2020.

The experiment was conducted under greenhouse condition using twelve (12) improved lines of tomato and two (2) local check varieties as shown in Table 1 and repeated.

A Randomized Complete Block Design (RCBD) with three replications and a planting distance of 0.3 m × 1.3 m were used. Seedlings of each tomato line/variety was raised and transplanted after three weeks into black polythene bags (9 × 14 inches) filled with cocopeat obtained from Hortirite Ventures, Tema-Ghana. For each tomato line/variety, 12 uniform seedlings were transplanted for each of the three (3) blocks obtaining a total of 504 plants.

Two separate experiments were carried out. The first experiment was between September 2019 and January 2020 while the second experiment was between January and June 2020. Agronomic practices such as watering, trellising, and pruning were done as and when necessary.

Table 1
Tomato lines/varieties, designated names, and their sources.

LINES/ VARIETIES	DESIGNATED NAME	GENETIC NATURE	SOURCE
BS731824	B24	Hybrid	EACi (ISRAEL)
BS731825	B25	Hybrid	EACi (ISRAEL)
BS731843	B43	Hybrid	EACi (ISRAEL)
BS731844	B44	Hybrid	EACi (ISRAEL)
BS731845	B45	Hybrid	EACi (ISRAEL)
BS731846	B46	Hybrid	EACi (ISRAEL)
BS731847	B47	Hybrid	EACi (ISRAEL)
BS731848	B48	Hybrid	EACi (ISRAEL)
JIFA 135	J135	Hybrid	CHINA
JIFA 137	J137	Hybrid	CHINA
JIFA 138	J138	Hybrid	CHINA
JIFA 142	J142	Hybrid	CHINA
NKANSAH HT	HT	Open Pollinated	FOHCREC
ANNA F1	ANNA	Hybrid	MACROFERTIL (TEMA)

*EACi – Eisenberg Agri Company (Israel).

Through drip irrigation, 10 g of phosphate and 12 g of N: P: K (10:5:20) fertilizers were applied per plant at the vegetative stage and reproductive stages respectively. Foliar application of B-naphthoxyacetic acid (3 ml/L) was applied twice a week between 4 and 9 weeks after transplanting to enhance fruit set. Data were collected from five tagged plants in the middle rows at the vegetative, reproductive and harvesting stages. Data were taken at 2, 4, 6 weeks and after harvest. Data were collected on plant height using a meter rule, number of leaves per plant, stem girth using a pair of vernier caliper, days to 50% flowering, number of fruits per plant, fruit weight and fruit yield per plant. Data on number of trusses per plant, flowers per truss and fruits per truss were collected as done by Nkansah et al., [18]. After harvesting, fruit quality traits such as Brix, titratable acidity, pericarp thickness, shelf life and fruit firmness were also taken.

Ripe tomato fruits were harvested by handpicking. The prevalent climatic conditions present at the experiment site were recorded (Table 2). The mean fruit weight (kg) for each of the five tagged plants was used to estimate the yield on plant basis (weight unit/plant). For total dry weights, the fresh leaves, stem and roots for each of the five tagged plants were collected and oven-dried at 70 °C for 72 h and weighed. Relative Growth Rate (RGR), defined as the increase in dry mass per unit of plant mass over a specified period of time was calculated using the formula below as reported by Ref. [19]:

$$RGR(g/day) = \frac{InW_f - InW_i}{(T_2 - T_1)}$$

Net Assimilation Rate (NAR) which is the measurement of the photosynthetic efficiency of plants was calculated using the formula below as reported by Ref. [19]:

$$NAR(gcm^{-2}/day) = \frac{(W_f - W_i) \times (InA_f - InA_i)}{(T_2 - T_1) (A_i - A_f)}$$

where:

W_f = Final dry weight after harvest

W_i = Initial dry weight at 2 Weeks

A_f = Leaf area at reproductive stage at 6 Weeks

A_i = Leaf area at vegetative stage at 2 Weeks

T₂ - T₁ = Time lapse between the vegetative stage and reproductive stage

For titratable acidity, the pH of 5 mls of diluted tomato macerate for different treatments was taken, after which it was titrated with 0.1 N Sodium hydroxide. The normality of the sodium hydroxide was determined. Titratable acidity was calculated using the formula below:

Table 2
Mean values of temperature and relative humidity in the greenhouse during the experimental period.

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)
September 2019	29.2	22.8	78.2	63.4
October 2019	31.4	24.2	77.3	61.2
November 2019	32.4	25.1	78.6	62.5
December 2019	33.1	24.3	79.8	64.0
February 2020	34.6	25.9	81.0	66.4
March 2020	35.5	24.3	82.0	66.2
April 2020	33.5	25.5	79.4	65.3
May 2020	34.7	26.5	81.3	66.3
June 2020	33.6	27.1	76.5	65.4

Source: FOHCREC Greenhouse thermohydrometer, Okumaning – Kade.

$$\text{Citric acid} = \frac{(\text{Volume of NaOH} \times \text{Normality of NaOH} \times \text{Meq of acid weight}) \times 100}{\text{Volume of sample titrated}}$$

Meq Weight of acid = Milliequivalent of the acid which is 0.064 for citric acid.

The tip of the penetrometer was gently pushed entirely into the five tomato fruit samples selected per line/variety to determine the fruit firmness. A vernier caliper was used to measure the thickness of the pericarp of five selected tomato fruits per line/variety. Also, after harvesting, five tomato fruits from each line/variety per replication were stored at room temperature 25–31 °C and relative humidity of 30–50%. The number of days it took each fruit to rot at room temperature was recorded as its shelf life.

2.2. Data analysis

Data were analyzed using GenStat statistical software version 19.0 and the least significant difference (LSD) at 5% was used in separating means.

3. Results

Significant differences were observed in plant height of the tomato genotypes (lines and varieties) evaluated for the two seasons (Table 3). Genotype B24 was the tallest followed by B25, while Nkansah HT was the shortest at 2 WAT, 4WAT and 6WAT in both seasons. Likewise, there were significant differences in stem girth among the genotypes (Table 4) at 2, 4 and 6WAT in experiment 1. Nkansah HT and B45 had the thickest and thinnest stem girths, respectively at 6WAT in experiment 1. However, there were no significant differences recorded in the stem girth of the tomato genotypes in experiment two at 4WAT and 6WAT (Table 4).

Regarding the number of days to 50% flowering and fruiting, significant differences were observed among the tomato genotypes (Table 5). Nkansah HT significantly had the shortest number of days to 50% flowering and fruiting in both experiments whereas genotype B25 had the longest number of days to 50% flowering in experiment 1. In addition, genotype J142 had the shortest number of days to 50% fruiting in experiment 1 as well as genotypes B24 and B45 in experiment 2.

Table 3

Plant height at 2WAT, 4WAT and 6 WAT of 14 tomato lines/varieties grown under greenhouse condition.

Lines/Varieties	2 WAT		4 WAT		6 WAT	
	Plant Height (cm)					
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	37.4 ± 1.4	28.1 ± 0.5	105.8 ± 5.4	58.4 ± 15.4	171.4 ± 5.1	129.5 ± 18.3
B25	34.0 ± 7.2	28.1 ± 0.9	87.6 ± 22.1	84.7 ± 8.5	143.8 ± 38.5	156.8 ± 20.5
B43	31.9 ± 3.2	19.2 ± 3.6	88.3 ± 6.9	58.3 ± 16.5	155.3 ± 11.4	122.2 ± 27.5
B44	26.3 ± 5.0	18.7 ± 2.9	69.8 ± 18.0	63.3 ± 7.5	126.5 ± 9.9	134.4 ± 16.1
B45	27.8 ± 5.0	20.1 ± 3.5	68.3 ± 24.7	63.5 ± 5.1	126.4 ± 7.5	115.5 ± 9.8
B46	32.1 ± 2.6	17.8 ± 3.1	97.0 ± 6.3	60.3 ± 3.6	130.9 ± 42.2	119.5 ± 15.2
B47	32.9 ± 1.4	19.2 ± 3.1	91.1 ± 4.6	60.2 ± 14.9	142.1 ± 10.8	119.9 ± 11.6
B48	29.8 ± 1.0	19.0 ± .2	89.7 ± 6.1	65.2 ± 6.6	144.7 ± 6.0	113.5 ± 7.7
J135	31.8 ± 2.7	22.6 ± 3.8	82.1 ± 6.8	55.2 ± 13.1	137.9 ± 9.6	120.1 ± 25.0
J137	26.9 ± 2.2	26.3 ± 7.1	73.6 ± 9.3	58.4 ± 15.5	130.0 ± 7.2	104.9 ± 18.7
J138	32.6 ± 0.8	18.5 ± 2.9	83.0 ± 4.0	53.4 ± 1.6	140.6 ± 5.3	111.5 ± 11.8
J142	30.3 ± 2.3	19.0 ± 3.4	82.7 ± 5.9	64.6 ± 2.4	140.2 ± 3.5	120.6 ± 6.6
ANNA	33.7 ± 1.3	22.5 ± 2.8	91.5 ± 3.9	59.8 ± 9.8	148.3 ± 1.7	124.2 ± 8.4
HT	21.1 ± 3.2	15.8 ± 2.4	59.2 ± 5.9	47.9 ± 9.9	81.1 ± 6.8	88.1 ± 11.9
LSD	5.7	6.3	19.8	18.2	26.1	23.3
$P \leq 0.05$	<0.001	0.007	0.005	0.109	<0.001	0.002

WAT: Weeks After Transplanting; LSD: Least Significant Difference.

Significant differences ($P \leq 0.05$) were observed in the total dry weight of the tomato genotypes for the two seasons (Table 6). ANNA F1 had a significantly higher total dry weight, while Genotype J142 had a lower total dry weight at 2WAT in experiment 1 (Table 6).

However, there were no significant differences observed in total dry weight of the genotypes in experiments 1 and 2 at 4WAT and 6WAT and at 2WAT for experiment 2 (Table 6).

For the Relative Growth Rate (RGR) and Net Assimilation Rate (NAR), significant differences ($P \leq 0.05$) were observed among the genotypes (lines and varieties) (Table 7). Genotype B43 followed by Genotype J138 and Genotype J137 significantly had a higher RGR, while Genotype B24 and Genotype B47 had a lower RGR in experiment 2 (Table 7). Furthermore, Genotype J138 had a significantly higher NAR, while Genotype B47 had a lower NAR in experiment 2 (Table 7).

However, there were no significant differences recorded in the Relative Growth Rate and the Net Assimilation Rate among the genotypes in experiment 1 (Table 7).

Moreover, significant differences ($P \leq 0.05$) among the tomato genotypes were observed in number of trusses per plant, number of flowers per truss and number of fruits per truss (Table 8). In both experiments, Nkansah HT significantly recorded the highest number of trusses per plant (Table 6). Again, Nkansah HT and J142 recorded the highest number of flowers per truss while J137 and J138 had the least number of flowers per truss in both experiments (Table 8).

In experiment 1, genotype J142 significantly recorded the highest number of fruits per truss while the lowest was recorded in B44, B46 and J138. In experiment 2, Nkansah HT and B25 had the highest number of fruits per truss. On the other hand genotypes B24, B44, B46, B47, B48, J135, J137, J142, J138 and Anna recorded the lowest number of fruits per truss in experiment 2 (Table 8).

Significant differences were observed in the number of fruits per plant and fruit weight among the genotypes in both experiments (Table 9). Nkansah HT significantly recorded a highest number of fruits per plants in both experiments, while Genotypes J135 and B24 recorded least number of fruits per plant respectively (Table 9). In addition, Genotypes J135 and J138 recorded the heaviest fruits in experiment 1 and 2 respectively, while Nkansah HT recorded the lightest fruit weight

Table 4
Stem girth at 2WAT, 4WAT and 6 WAT of 14 tomato lines/varieties grown under greenhouse conditions.

Lines/Varieties	2 WAT		4 WAT		6 WAT	
	Stem Girth (mm)					
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	0.59 ± 0.04	0.42 ± 0.02	0.63 ± 0.05	0.42 ± 0.12	0.69 ± 0.01	0.60 ± 0.03
B25	0.50 ± 0.14	0.47 ± 0.04	0.51 ± 0.08	0.52 ± 0.06	0.64 ± 0.07	0.65 ± 0.13
B43	0.49 ± 0.06	0.40 ± 0.08	0.55 ± 0.06	0.48 ± 0.04	0.64 ± 0.05	0.59 ± 0.05
B44	0.49 ± 0.05	0.39 ± 0.06	0.58 ± 0.13	0.52 ± 0.01	0.74 ± 0.09	0.69 ± 0.10
B45	0.45 ± 0.09	0.44 ± 0.02	0.52 ± 0.07	0.48 ± 0.02	0.47 ± 0.06	0.63 ± 0.07
B46	0.52 ± 0.03	0.34 ± 0.04	0.65 ± 0.06	0.47 ± 0.01	0.77 ± 0.06	0.60 ± 0.04
B47	0.46 ± 0.07	0.34 ± 0.06	0.59 ± 0.07	0.43 ± 0.07	0.74 ± 0.09	0.61 ± 0.04
B48	0.56 ± 0.05	0.37 ± 0.06	0.63 ± 0.07	0.46 ± 0.03	0.71 ± 0.03	0.55 ± 0.04
J135	0.64 ± 0.07	0.46 ± 0.03	0.73 ± 0.09	0.49 ± 0.04	0.80 ± 0.05	0.69 ± 0.08
J137	0.53 ± 0.11	0.45 ± 0.03	0.63 ± 0.09	0.48 ± 0.04	0.76 ± 0.13	0.60 ± 0.06
J138	0.56 ± 0.01	0.38 ± 0.12	0.52 ± 0.03	0.46 ± 0.01	0.75 ± 0.05	0.64 ± 0.07
J142	0.47 ± 0.05	0.33 ± 0.04	0.53 ± 0.03	0.47 ± 0.02	0.66 ± 0.05	0.64 ± 0.07
ANNA	0.55 ± 0.07	0.41 ± 0.08	0.70 ± 0.08	0.46 ± 0.07	0.81 ± 0.05	0.67 ± 0.02
HT	0.62 ± 0.04	0.41 ± 0.06	0.81 ± 0.10	0.53 ± 0.09	0.88 ± 0.06	0.66 ± 0.04
LSD	0.11	0.08	0.12	0.09	0.11	0.10
$P \leq 0.05$	0.048	0.017	<0.001	0.389	0.006	0.212

WAT: Weeks After Transplanting; LSD: Least Significant Difference.

Table 5
Number of days to 50% flowering and fruiting of 14 tomato lines/varieties grown under greenhouse conditions.

Lines/ Varieties	Days to 50% Flowering		Days to 50% Fruiting	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	42 ± 3	33 ± 3	57 ± 2	60 ± 2
B25	47 ± 3	40 ± 2	56 ± 4	57 ± 2
B43	30 ± 2	34 ± 2	54 ± 2	56 ± 1
B44	30 ± 1	35 ± 3	53 ± 3	56 ± 4
B45	35 ± 2	38 ± 2	64 ± 3	60 ± 1
B46	38 ± 3	36 ± 4	53 ± 2	55 ± 1
B47	31 ± 1	36 ± 2	53 ± 2	54 ± 3
B48	30 ± 2	32 ± 2	47 ± 4	49 ± 4
J135	36 ± 3	33 ± 3	47 ± 1	47 ± 1
J137	33 ± 2	31 ± 1	48 ± 2	51 ± 2
J138	30 ± 1	32 ± 3	49 ± 3	52 ± 2
J142	36 ± 2	36 ± 2	67 ± 6	65 ± 1
ANNA	34 ± 1	33 ± 3	53 ± 3	52 ± 2
HT	24 ± 1	22 ± 1	36 ± 2	39 ± 1
LSD	2	4	5	4
$P \leq 0.05$	<0.001	<0.001	<0.001	<0.001

LSD: Least Significant Difference.

Table 6
Total dry weight of 14 tomato lines/varieties grown under greenhouse conditions.

Lines/Varieties	2WAT		4WAT		6WAT	
			Total dry weight (kg)			
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	2.17 ± 0.6	0.37 ± 0.1	12.4 ± 10.8	13.0 ± 8.9	25.2 ± 1.7	19.3 ± 12.0
B25	0.93 ± 0.2	0.73 ± 0.4	13.0 ± 8.9	15.8 ± 11.2	35.7 ± 7.5	40.5 ± 4.4
B43	2.40 ± 0.3	0.37 ± 0.1	20.3 ± 4.2	10.2 ± 5.1	41.7 ± 1.2	39.1 ± 2.3
B44	1.50 ± 1.2	0.60 ± 0.2	15.8 ± 11.2	17.2 ± 8.9	33.8 ± 2.1	39.0 ± 4.3
B45	2.40 ± 0.8	0.53 ± 0.2	27.1 ± 10.6	27.1 ± 10.6	49.1 ± 5.5	26.4 ± 1.9
B46	2.20 ± 0.7	0.47 ± 0.1	17.5 ± 16.1	16.0 ± 5.3	31.0 ± 0.2	35.2 ± 8.7
B47	1.63 ± 1.0	0.67 ± 0.2	13.6 ± 8.7	13.3 ± 0.7	34.4 ± 7.0	26.6 ± 4.4
B48	1.47 ± 0.8	0.57 ± 0.2	16.0 ± 5.3	12.4 ± 10.8	41.9 ± 3.0	23.3 ± 2.0
J135	2.37 ± 0.5	0.63 ± 0.2	13.3 ± 0.7	13.7 ± 8.9	44.4 ± 3.1	40.1 ± 0.9
J137	1.63 ± 1.1	0.47 ± 0.2	10.2 ± 5.1	20.3 ± 4.2	38.9 ± 2.7	47.4 ± 3.6
J138	2.10 ± 0.5	0.47 ± 0.1	13.5 ± 6.8	13.6 ± 8.7	35.7 ± 1.8	46.8 ± 1.3
J142	0.63 ± 0.1	0.13 ± 0.1	13.7 ± 8.9	17.5 ± 16.1	33.7 ± 3.9	30.4 ± 19.2
ANNA	2.47 ± 0.8	0.53 ± 0.1	16.9 ± 9.1	13.3 ± 6.8	43.3 ± 1.7	43.0 ± 5.0
HT	2.37 ± 0.5	0.47 ± 0.2	13.3 ± 3.4	13.5 ± 3.4	34.1 ± 4.6	45.2 ± 4.8
LSD	1.16	0.68	14.3	14.2	20.4	21.0
$P \leq 0.05$	0.046	0.953	0.72	0.713	0.665	0.148

WAT: Weeks After Transplanting; LSD: Least Significant Difference.

in both experiments (Table 9). Likewise, Genotype J138 significantly had a highest fruit yield, while Genotype B25 had a lower fruit yield in experiment 1 (Table 9). Furthermore, for fruit yield in experiment 2, Genotype B25 was significantly higher than that of Genotype B24 (Table 9).

Significant ($P \leq 0.05$) differences were observed the mean pH, Brix and titratable acidity of tomato lines/variety among the genotypes. All the genotypes except B44, J138 and variety, Anna had significantly higher pH than Nkansah HT in experiment 1. However, in experiment 2, Nkansah HT, B24 and B28 had significantly higher pH than the other genotypes. (Table 10).

With respect to the Brix, B25 had significantly higher Brix than the other genotypes except B24, B43, B46, and B47 experiment 1. On the other hand, in experiment 2, there were no significant differences in the Brix among the genotypes. Also, significant differences were observed in titratable acidity (TTA) among the tomato lines and varieties in experiment 1 (Table 10). Genotypes B44 and B45 had significantly higher titratable acidity than lines B47, J135, J137, J138 and Nkansah HT, but had similar titratable acidity to that of lines B24, B25, B43, B46, B48, J142 and variety ANNA in experiment 1. In experiment 2 however, there were no significant differences in titratable acidity among the genotypes.

Table 7

Relative Growth Rate and Net Assimilation Rate of 14 tomato lines/varieties grown under greenhouse conditions.

Lines/ Varieties	Relative Growth Rate (g/day)		Net Assimilation Rate (g cm ⁻² / day)	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	0.08 ± 0.01	0.04 ± 0.01	0.10 ± 0.05	0.15 ± 0.03
B25	0.13 ± 0	0.15 ± 0.01	0.14 ± 0.01	0.35 ± 0.01
B43	0.10 ± 0	0.17 ± 0.01	0.12 ± 0.01	0.65 ± 0.02
B44	0.11 ± 0.01	0.09 ± 0.01	0.12 ± 0	0.18 ± 0.01
B45	0.11 ± 0.01	0.10 ± 0.1	0.12 ± 0.01	0.37 ± 0.01
B46	0.09 ± 0.01	0.10 ± 0.05	0.10 ± 0.05	0.38 ± 0.01
B47	0.11 ± 0.01	0.04 ± 0.01	0.12 ± 0	0.07 ± 0.01
B48	0.12 ± 0.01	0.08 ± 0.01	0.14 ± 0.01	0.15 ± 0
J135	0.11 ± 0	0.15 ± 0.01	0.12 ± 0.01	0.50 ± 0.05
J137	0.12 ± 0	0.17 ± 0.01	0.14 ± 0.01	0.74 ± 0.01
J138	0.10 ± 0.01	0.17 ± 0.01	0.12 ± 0	0.77 ± 0
J142	0.14 ± 0.01	0.05 ± 0	0.17 ± 0.01	0.09 ± 0
ANNA	0.10 ± 0	0.16 ± 0.1	0.12 ± 0.01	0.61 ± 0
HT	0.10 ± 0.01	0.16 ± 0.01	0.11 ± 0	0.69 ± 0.01
LSD	0.04	0.10	0.05	0.31
P ≤ 0.05	0.360	0.045	0.419	<0.001

LSD: Least Significant Difference.

There were no significant differences in fruit firmness among the tomato genotypes in experiments 1 and 2 (Table 11). Regarding pericarp thickness, tomato variety ANNA had significantly thicker pericarp than Nkansah HT as well as lines B48 and J135 in experiment 1. Similar observation was seen in experiment 2 (Table 11). Shelf life differed significantly among the tomato genotypes in both experiments (Table 11). Genotypes B45, J138, and ANNA had significantly longer shelf life than Nkansah HT, lines B24, B43, B46, B47, B48, and J142 in experiment 1. In experiment 2, ANNA, J138, B44, B25 had significantly longer shelf life than genotypes J135 and J137.

4. Discussion

In this study, improved tomato genotypes (lines and varieties) were assessed under greenhouse conditions to identify their agronomic performances and fruit quality attributes. It was observed that the tomato lines particularly line J138 with significantly higher relative growth rate (RGR) also had higher net assimilation rate (NAR) which consequently increased the dry matter production. Plant productivity is influenced by both genetic and environmental factors, serving as one of the most important indicators of plant growth and development because it affects various ecological processes [20]. Hence in this study, the significant

Table 8

Number of trusses per plant, number of flowers per truss and number of fruits per truss of 14 tomato lines/varieties grown under greenhouse conditions.

Lines/Varieties	Number of trusses per plant		Number of flowers per truss		Number of fruits per truss	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	5 ± 1	4 ± 1	5 ± 0	5 ± 1	5 ± 1	4 ± 1
B25	4 ± 0	5 ± 1	5 ± 1	6 ± 1	5 ± 1	6 ± 1
B43	5 ± 1	4 ± 0	5 ± 0	5 ± 0	5 ± 1	5 ± 1
B44	5 ± 0	6 ± 1	5 ± 1	5 ± 1	4 ± 1	4 ± 1
B45	4 ± 1	5 ± 1	7 ± 1	5 ± 1	6 ± 1	5 ± 1
B46	5 ± 1	4 ± 1	5 ± 1	5 ± 1	4 ± 1	4 ± 0
B47	5 ± 1	4 ± 1	5 ± 0	5 ± 1	5 ± 1	4 ± 1
B48	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	4 ± 1
J135	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	4 ± 1
J137	5 ± 1	5 ± 1	5 ± 0	4 ± 1	5 ± 1	4 ± 0
J138	6 ± 1	6 ± 1	4 ± 0	5 ± 1	4 ± 1	4 ± 1
J142	7 ± 1	6 ± 1	8 ± 1	7 ± 1	8 ± 1	4 ± 0
ANNA	5 ± 0	5 ± 1	6 ± 1	5 ± 1	5 ± 1	4 ± 1
HT	16 ± 2	17 ± 3	8 ± 2	8 ± 1	6 ± 1	6 ± 0
LSD	1	1	1	1	1	1
P ≤ 0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD: Least Significant Difference.

differences observed in the performances of some tomato genotypes could be attributed to the genetic and environmental effects. This suggests that, there are inherent genetic variations in photosynthetic capabilities among the genotypes, which is also influenced by the prevailing environmental conditions [21]. A measure of photosynthetic efficiency of plants is net assimilation rate (NAR). Thus, the productive efficiency of plants expressed as the increase in total dry weight per unit leaf area. The net increase in photosynthetic efficiency in some of the genotypes suggests that they are more efficient in absorbing sunlight for various photosynthetic carbon metabolism and related processes which is translated into dry matter production [22]. Also, the variations in plant height could be attributed to the inherent genetic make-up among the genotypes. Plant height is one of the good indices of plant vigour which may contribute immensely to plant productivity [23]. Apart from genetic variability being a contributing factor to plant height, the prevailing environmental conditions may as well account for the variations [24]. In addition, an increase in plant height could lead to an increase in stem girth thereby enhancing the plant's resistance to lodging [25].

In general, higher fruit numbers increase yield while lowering average fruit weight, whereas lower fruit numbers increase fruit size and quality while lowering yield. Nkansah HT's ability to tolerate heat stress is confirmed by an increase in flower and fruit numbers at an average

Table 9

Number of fruits per plant and fruit yield (kg/plant) of 14 tomato lines/varieties grown under greenhouse condition.

Lines/ Varieties	Number of Fruits per plant		Fruit yield (kg/plant)	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	7 ± 1	5 ± 2	9.57 ± 3.21	7.44 ± 1.91
B25	4 ± 1	10 ± 3	7.64 ± 2.81	8.70 ± 1.52
B43	6 ± 1	5 ± 3	5.62 ± 1.36	7.45 ± 0.33
B44	5 ± 1	7 ± 2	8.72 ± 2.32	7.27 ± 3.83
B45	7 ± 1	6 ± 1	5.75 ± 0.97	7.31 ± 1.36
B46	7 ± 2	9 ± 3	7.87 ± 3.16	5.97 ± 0.89
B47	4 ± 1	5 ± 2	7.03 ± 0.79	6.84 ± 1.08
B48	6 ± 3	5 ± 1	6.79 ± 0.99	7.84 ± 0.84
J135	3 ± 1	6 ± 1	14.75 ± 2.02	11.36 ± 0.75
J137	4 ± 1	5 ± 1	10.45 ± 3.54	8.65 ± 2.61
J138	6 ± 3	5 ± 1	11.28 ± 0.78	14.68 ± 1.18
J142	11 ± 4	7 ± 0	5.26 ± 2.59	5.24 ± 2.02
ANNA	20 ± 2	10 ± 1	5.07 ± 0.87	5.71 ± 1.40
HT	27 ± 2	36 ± 12	1.76 ± 0.55	1.75 ± 0.17
LSD	2	2	3.25	2.06
P ≤ 0.05	<0.001	<0.001	<0.001	<0.001

LSD: Least Significant Difference.

Table 10
pH, Total Soluble Solids (brix) and Titratable Acidity of 14 tomato lines/varieties under greenhouse conditions.

Lines/Varieties	pH		TSS (%)		Titratable Acidity (g/L)	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	4.43 ± 0.12	4.60 ± 0.00	5.13 ± 0.13	5.80 ± 0.87	1.973 ± 0.13	1.813 ± 0.15
B25	4.57 ± 0.10	4.53 ± 0.06	6.85 ± 1.31	5.77 ± 1.85	1.941 ± 0.07	1.741 ± 0.19
B43	4.43 ± 0.06	4.37 ± 0.06	4.97 ± 0.53	5.00 ± 0.62	1.968 ± 0.11	1.805 ± 0.07
B44	4.32 ± 0.08	4.27 ± 0.15	4.78 ± 0.67	5.07 ± 0.61	2.096 ± 0.06	1.904 ± 0.13
B45	4.62 ± 0.06	4.47 ± 0.06	4.80 ± 0.96	3.90 ± 0.20	2.128 ± 0.13	2.029 ± 0.23
B46	4.55 ± 0.17	4.40 ± 0.00	5.33 ± 0.68	4.80 ± 0.85	1.917 ± 0.05	1.848 ± 0.09
B47	4.57 ± 0.10	4.50 ± 0.10	5.38 ± 0.54	4.37 ± 0.47	1.702 ± 0.07	1.595 ± 0.16
B48	4.48 ± 0.06	4.63 ± 0.12	4.62 ± 0.33	3.83 ± 0.38	1.920 ± 0.08	1.861 ± 0.03
J135	4.50 ± 0.05	4.37 ± 0.06	4.68 ± 0.18	4.47 ± 0.72	1.704 ± 0.09	1.667 ± 0.19
J137	4.47 ± 0.06	4.37 ± 0.06	4.87 ± 0.73	3.40 ± 1.11	1.811 ± 0.04	1.739 ± 0.11
J138	4.28 ± 0.13	4.37 ± 0.12	4.77 ± 0.35	5.37 ± 1.38	1.722 ± 0.12	1.675 ± 0.21
J142	4.57 ± 0.10	4.20 ± 0.10	3.87 ± 0.23	4.60 ± 0.72	1.933 ± 0.07	1.768 ± 0.12
ANNA	4.58 ± 0.06	4.30 ± 0.00	4.62 ± 0.72	4.70 ± 0.35	2.013 ± 0.12	1.925 ± 0.17
HT	4.25 ± 0.09	4.73 ± 0.32	4.45 ± 0.28	4.17 ± 0.06	1.736 ± 0.06	1.733 ± 0.13
LSD	0.16	0.20	1.09	1.47	0.149	0.262
<i>P</i> ≤ 0.05	<0.001	<0.001	0.006	0.067	<0.001	0.136

LSD: Least Significant Difference.

Table 11
Fruit firmness, pericarp thickness and shelf life of 14 tomato lines/varieties under greenhouse conditions.

Lines/Varieties	Fruit Firmness (kg/f)		Pericarp thickness (mm)		Shelf life (Days)	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
B24	8.03 ± 1.01	6.62 ± 1.32	0.50 ± 0.05	0.5 ± 0.05	24 ± 4	24 ± 4
B25	7.02 ± 0.60	5.08 ± 1.22	0.57 ± 0.08	0.5 ± 0.10	29 ± 5	27 ± 4
B43	6.38 ± 1.25	6.56 ± 1.70	0.53 ± 0.06	0.50 ± 0.05	25 ± 6	26 ± 4
B44	5.14 ± 0.64	7.44 ± 1.71	0.48 ± 0.08	0.47 ± 0.08	29 ± 7	28 ± 6
B45	4.48 ± 1.85	5.32 ± 1.01	0.55 ± 0.13	0.62 ± 0.10	34 ± 4	22 ± 15
B46	8.89 ± 0.90	3.63 ± 1.78	0.55 ± 0.09	0.55 ± 0.05	26 ± 6	22 ± 4
B47	5.90 ± 0.76	6.74 ± 3.35	0.62 ± 0.10	0.53 ± 0.08	25 ± 6	25 ± 7
B48	4.23 ± 4.40	6.89 ± 3.67	0.45 ± 0.05	0.43 ± 0.10	22 ± 3	23 ± 1
J135	3.18 ± 1.11	2.86 ± 1.13	0.35 ± 0.05	0.42 ± 0.08	12 ± 2	13 ± 2
J137	6.99 ± 1.16	2.46 ± 1.70	0.55 ± 0.05	0.52 ± 0.08	15 ± 5	14 ± 2
J138	9.07 ± 4.16	7.94 ± 0.12	0.52 ± 0.03	0.52 ± 0.03	31 ± 3	33 ± 3
J142	6.65 ± 0.20	5.02 ± 3.40	0.48 ± 0.03	0.50 ± 0.1	26 ± 4	25 ± 3
ANNA	11.25 ± 5.17	9.71 ± 1.10	0.68 ± 0.03	0.67 ± 0.03	38 ± 3	36 ± 1
HT	4.69 ± 0.76	3.32 ± 0.83	0.38 ± 0.08	0.42 ± 0.08	22 ± 3	24 ± 2
LSD	10.71	8.62	0.12	0.13	7	9
<i>P</i> ≤ 0.05	0.109	0.209	<0.001	0.025	<0.001	0.002

LSD: Least Significant Difference.

temperature of 25–36° Celsius [26]. Only J142 showed similar responses and flowered early among the improved lines evaluated particularly in experiment 1. Although early flowering may be due to the varietal genetic makeup, the high environmental temperature may cause rapid growth and development in the reproductive parts of the plant [27]. Nevertheless, parental lines of J142 could be a useful genetic resource in the development of heat-tolerant and early maturing tomato varieties in Ghana. The parental lines with predetermined breeding values will be obtained from AVRDC. Alternatively, the breeding potential of J142 can be exploited to generate new inbred lines with heat tolerant characteristics via pedigree selection [28]. Despite having a small fruit weight, it was at least three times heavier than the local check, Nkansah HT. This is an added benefit of the J142, as it can be used for both fresh and whole-fruit tomato cannery. The highest yield was obtained from genotype J138, J135 and J137 compensating their fruit numbers for increased fruit weight. As suggested by Ref. [27], fruit weight, fruit trusses per plant, and number of fruits per plant all have a direct correlation with fruit yield. By reducing the number of fruits per truss, the average fruit weight and quality were both improved. And thus, as the number of fruits per truss was reduced, yield increased. This is due to the fact that as the number of tomato fruits per truss increases, so does the yield per plant, and smaller fruits become more prevalent. Low yields for some tomato lines or varieties may be due to the failure of flowers to develop into fruits, as seen in experiment 2, and [29]

attributes this to tomato flowers' high sensitivity to high temperatures during the flowering and early fruiting stages. The differences in yield values between experiments one and two could be due to the differences in the fruit weight as well as the number of fruit, which are both significantly and positively correlated (data not shown). As suggested by Isa et al. [30], the number of fruits per plant is the highest contributor to fruit yield and selection of such trait could be useful towards yield improvement.

5. Fruit quality traits are important in both processing and fresh market tomatoes. Fresh tomato quality is determined by firmness, colour, and taste, which are related to ripeness and shelf life [31]. However, according to Refs. [30,31], changes in fruit quality traits such as firmness, total soluble solids and acid contents have been attributed to moisture stress [32]. As a result, in this study, the genetic make-up of the genotype influenced the high total soluble solid (TSS), which is an important quality character, and one of the main factors contributing to tomato flavour [33,34] which affects consumer preferences and industrial performance [35]. The average TSS for the tomato lines B25, B24, B46, J138, B43, B44 ranging from 6.3 to 5 could be useful for tomato paste processing [36] as well as home consumption for salad, stew and soup preparations. While both genetic and environmental (growing conditions) factors can contribute to the significant variations in pH and titratable acidity. According to Ref. [37], tomato fruits with a pH of less than 4.5 are considered acidic, classifying all the evaluated tomato

lines/varieties with a pH ranging 4.3 to 4.6 as acidic to slightly acidic (including; B24, B25, B45, B46, B47, B48, J135 and Nkansah HT), respectively. This could be due to high levels of citric, malic, and oxalic acid accumulation rather than high levels of ascorbic acid, fructose, glucose, and sucrose synthesis under high temperatures [36]. Firmness is described as the texture of fruits where firm tissues are desirable in produce consumed fresh or minimally processed [38]. Even though there were no significant differences in fruit firmness, genotypes with thick pericarps, such as Anna and J138, had a long shelf life, implying good physical and visual fruit quality. The differences in fruit firmness for Anna and J138 for both experiments could be due to the increase in temperature from 31.5 °C in experiment 1–34.6 °C in experiment 2. A similar trend was observed by Ref. [39], in strawberry fruits where a 1 °C increase in temperature resulted in a decrease in fruit firmness. In addition, a slight difference in storage conditions (room temperature condition) could be a possible contribution to the observed differences. Prolonged exposure to certain storage conditions can hasten the loss of fruit firmness which can be attributed to high rates of respiration, fruit senescence, degradation of polysaccharides and cell wall softening enzymatic activities [40–42].

5. Conclusion

Under greenhouse conditions, the improved tomato genotypes (lines or varieties) evaluated showed different but distinct genetic characteristics for their adaptability and usefulness in breeding and cultivation. Lines J138 and B24 recorded the highest yields (20.05 t/ha and 23.03 t/ha respectively). Lines B24, B25, J138, B45 and B46 also exhibited good fruit quality traits such as pH, pericarp thickness, fruit firmness and shelf life. Hence, these tomato lines could be utilized for household consumption as fresh tomato and industrial processing.

Author contributions

DCAA conducted experiment and drafted the manuscript, JNA and GON contributed to conceptualization of project, supervision and manuscript preparation. PAO and SON drafted manuscript and contributed to reviewing and editing of manuscript. FOA contributed to data analyses and writing of manuscript.

Statement of conflict of interest

The authors of our manuscript entitled “Evaluation of Agronomic Performances and Fruit Quality of Improved Tomato (*Solanum lycopersicum* L.) Lines under Greenhouse Conditions” submitted to the Journal of Agriculture and Food Research article in the Special Issue, Sustainable agriculture and food systems, thereby **declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.**

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