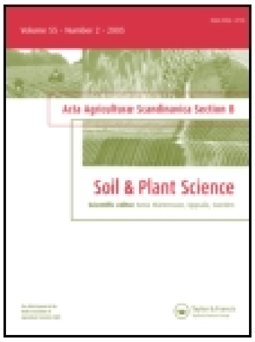

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ORIGINAL ARTICLE

Screening tomato genotypes for adaptation to high temperature in West Africa

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Tomato is an important vegetable widely grown in the tropics due to its nutritional value and financial benefits for farmers. In Ghana, there is an undersupply caused by production ceasing entirely from October to May due to high temperatures. Heat stress has been reported to cause excessive flower drop leading to drastic reduction in yield; however, genotypic differences in heat tolerance exist in tomato. A greenhouse experiment was conducted to screen 19 different tomato genotypes for their tolerance to heat stress. The genotypes were selected because they were the commercial varieties widely available to farmers. The average day and night temperatures recorded were 33.8°C and 25.9°C, respectively. Cultivars were evaluated for heat adaptation traits such as flower drop and number of fruits. There were highly significant differences between the genotypes for numbers of fruits per plant, ranging from 1 to 27. Fruit yield per plant ranged from 26.7 to 571.8 g. The locally developed open pollinated cultivar 'Nkansah' had the highest fruit number and fruit yield per plant, but produced the smallest sized fruits of only 25.2 g. Cultivars with large size fruits were 'Queen', 'DV 2962' and 'Wosowoso' with a combined average of 85.7 g. The first two principal components (PCs) accounted for 79.7% of total variation. The first PC had positive weights for number of flowers per truss, number of fruits per plant, total number of flowers, yield per plant and number of trusses. PC2 explained 11% of the total variability among genotypes and had positive weights for all traits except number of days to flowering and weight per fruit. The highly contrasting material on traits such as flower and fruit production under high temperatures can be used for further research to elucidate the physiological responses conferring adaptation to heat stress.

Keywords: germplasm; heat; horticulture; *Solanum lycopersicum*; stress

Introduction

Tomato (*Solanum lycopersicum*) is an important and the most widely grown vegetable in semi-arid regions including Ghana. It is used in soups and stews in several households, restaurants and hotels across the country. Not only are tomatoes a dietary source of vitamins A, C, E, β-carotene and lycopene (Closas et al. 2004), they are also a source of income for many small-scale farmers in the country. Over the years, there has been an increase in demand for exotic tomato cultivars. These exotic cultivars have better fruit quality than local cultivars, since they are well defined in shape have a firmer texture and are more fleshy, which is more suited for the western type of dishes such as fresh salads, pizzas, sandwiches and omelettes that have become increasingly popular in the country. The local tomato cultivars grown in the country are not suitable for such dishes because the fruits retain a lot of water, are less fleshy and have an irregular shape. Another advantage of the exotic tomato cultivars is that they have a longer storage life span than the local cultivars.

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Tomato thrives well under tropical and subtropical regions, it requires an optimum temperature within the range of 18–28°C to grow vigorously and stay productive (Saeed et al. 2007). Tomato production, including exotic cultivars, is restricted to the period from June to September due to high temperatures that persistently prevail outside this period sometimes exceeding 35°C during the day and 24°C during the night especially in southern Ghana. Tomato production ceases at high temperature and shortage of tomatoes as well as high prices are common in the country. Temperatures exceeding 35°C have been reported to be detrimental to seed germination, seedling and vegetative growth, flowering and fruit set and fruit ripening development in tomatoes (Wahid et al. 2007). Heat stress in tomato has been reported however to affect primarily the reproductive development (Sato et al. 2006) causing excessive flower drop, which leads to low fruit production. Firon et al. (2006) also report that day and night temperatures exceeding 28°C and 22°C, respectively, negatively affect tomato fruit yield.

Variability of adaptation of tomato cultivars to heat stress has been demonstrated using such traits as membrane thermostability, stigma elongation, antheridial cone splitting, number of flowers shed per plant and yield per plant (Saeed et al. 2007; Abdelmageed et al. 2009). Heat adaptation traits also include flower number, fruit number, fruit set, fruit weight and yield (Lin et al. 2006). The selection of crops or species with enhanced adaptation to heat stress would be the best and the easiest strategy for increasing fruit yield at high temperatures in tomato (Warner & Erwin 2005). Identification of tomato germplasm with adaptation to heat stress may firstly, provide cultivars that ensure continuous cultivation of tomato throughout the year and this may ultimately increase production of tomato; secondly, provide parental lines for future breeding programmes for improving tomato cultivars. A greenhouse experiment was therefore conducted with the objectives of identifying tomato genotypes with a high degree of tolerance to heat stress; evaluate tomato cultivars for variability in flower retention, flower drop and fruit yield under heat stress; and to distinguish tomato cultivars using multiple traits comparison through a principal component (PC) analysis bi-plot.

Materials and methods

Tomato cultivars were evaluated in a pot experiment in a greenhouse located in the Sinna's Garden of the Crop Science Department of the University of Ghana (UG), Legon, Accra; 97 m above sea level and on latitude 5°39′N, longitude 0°11′W. A total of 19 tomato cultivars were evaluated in this study (Table 1). 'Rio Grande VF', 'Tomato Rockstone VF', 'Caracoli', 'F1 Ninja', 'Tropimech', 'Petomech VF II Improved', 'Moneymaker' and 'Petomech' were selected based on the availability to farmers. Petomech is one of the most common varieties being cultivated in Ghana (Monney et al. 2009; Robinson & Kolavalli 2010). '18I', '17I' were germplasm obtained from The World Vegetable Centre (AVDRC), Taiwan (original names: 'CLN 2318 F' and 'CLN 2443B' respectively), 'King 5' and 'Queen' from Japan, '14 IR Island Red', '8S Selected SM1' and '5C Roma' from Samoa. These genotypes are used for research studies at the Crop Science Department of the UG. 'Nkansah' is a heat tolerant variety recently developed at Forest and Horticultural Crops Research Centre, Kade of UG. This variety has however had limited greenhouse and field trials. 'Wosowoso' and 'Champion' are varieties previously developed at the Crop Science Department, UG. 'Wosowoso' has been used extensively in research studies across different agro-ecological regions in the country and was readily adapted by farmers but due to poor fruit qualities, unpopular with consumers due to short life, more farmers are reluctant to cultivate it. 'DV 2962' is a heat tolerant hybrid developed by Seminis Monsanto, Thailand. Seeds were sown on 26 April 2010 in seed trays filled with decomposed media mixture of moist rice husk, sawdust and cow dung. The medium was in a ratio of 1:1:1 v/v/v rice husk to sawdust to manure. Two seeds were sown in each cell and lightly covered with the media and watered. After emergence, the necessary nursery management was done. The seedlings were transplanted into pots filled with 4 kg of soil. The soil used for the study was Keta series, a sandy soil classified as Arenosols according to ISSS/ISRIC/FAO (1998) and Psamments according to soil taxonomy. A sample of the soil was obtained from 0 to 15 cm depth. The physiochemical properties of the soil were as follows: 75% coarse sand, 10% fine sand, 0.5% silt and 2.4% clay, pH: 7.7, bulk density: 1.5 Mg/m^3, electrical conductivity (EC): 0.13 dS/m, 0.23% organic carbon, 0.098% Nitrogen (N), 123 mg/kg available Phosphorus (P) (Olsen), 1539 mg total P/kg. Transplanting was done on 25 May 2010. A starter solution of 15 g of NPK (where K is Potassium) (15:15:15) l of water was applied at a rate of 150 ml per pot at the time of transplanting. There were eight plants assessed for each cultivar arranged in completely randomised design on a bench in the greenhouse. In total, 152 pots were used. Table 2 gives the temperatures during the life span of the experiment.

Calcium nitrate (15.5% N, 19% Ca), Plant Prod fertilizer (18% N, 9% P, 27% K) were used to prepare the nutrient solution giving a full nutrient

Table 1. Tomato cultivars used in the study.

No.	Tomato cultivar	Origin
1	'Petomech'	Monarch Seed, Holland
2	'Rio Grande VF'	Griffaton Producteur Grainier, France
3	'Tomato Rockstone VF'	Griffaton Producteur Grainier, France
4	'Caracoli'	Griffaton Producteur Grainier, France
5	'F1 Ninja'	Technisem, France
6	'Tropimech'	Technisem, France
7	'Petomech VF II Improved'	Petoseed Seminis, Netherlands
8	'Moneymaker'	Griffaton Producteur Grainier, France
9	'King 5'	Japan
10	'Queen'	Japan
11	'18I (CLN 2318 F)'	AVDRC
12	'14IR Island Red'	Samoa Island
13	'8S Selected SM1'	Samoa Island
14	'5C Roma'	Samoa Island
15	'17I (CLN 2443B)'	AVDRC
16	'Nkansah'	Forest and Horticulture Crops Research Centre, Kade, University of Ghana
17	'DV-2962'	Seminis Monsanto, Thailand
18	'Champion'	Crop Science Department, University of Ghana
19	'Wosowoso'	Crop Science Department, University of Ghana

AVDRC: World Vegetable Centre.

supply including micro nutrients. A total of 1.5 kg and 1 kg of Plant Prod and calcium nitrate, respectively, were added to 2.5 l of water. Twenty-five millilitres of this nutrient solution with an EC of 2 dS/m were supplied to the plants a week after transplanting and was increased to EC of 4 dS/m from flowering onwards. The nutrient solution was applied three times a week. Plants were secured with plastic twine attached to an overhead wire. The insecticide Cydim super (AI: 36 g cypermethrin, 400 g dimethoate) and fungicide Bendazim (AI: carbendazim 500 g/kg) were used at the recommended rates to control pest and diseases.

Data were collected on the following putative heat tolerance traits: flower number as given by total number of flower primordia developed by 56 days after planting (DAP), fruit number, i.e. the total number of fruits harvested – only mature, red in colour fruits. Fruit yield as the total fruit weight in grams of each plant. Fruit weight as average fruit weight per plant obtained from 10 fruits randomly selected.

The data were subjected to analysis of variance and the differences between means were compared using the least significant difference (LSD). Correlation among traits was determined. The Genstat version 9.2 stat software (Genstat 2007) was used in the analyses.

For each genotype, mean values for the eight traits measured were used for PC analysis using XLSTAT (2010). The PCs whose eigenvalues were equal or greater than 1 were retained.

Table 2. Mean monthly temperature (°C) during the experimental period.

Month	Temperature		
	Maximum	Minimum	Mean
May	35.5	26.2	30.9
June	33.1	26.4	29.7
July	32.9	26.1	29.5
August	34.0	24.7	29.3

Results

The number of days to anthesis varied significantly ($P < 0.001$) among the genotypes (Table 3). 'Nkansah' flowered earlier than the other genotypes. The total number of trusses on a plant for a period of 2 months ranged from 5 to 14. 'Nkansah' had the highest number of trusses (14) at the end of 2 months and also showed the highest average number of flowers per truss (7) and total number of flowers (30). The least number of flowers recorded was 15 in 'Rio Grande VF', 'Rockstone VF', 'F1Ninja' and 'Queen'. Their number of flowers was not significantly different ($P > 0.05$) from 'Petomech', '18I' and '5C' and 'Wosowoso' which ranged from 16 to 20.

There were significant differences ($P < 0.001$) between the numbers of fruits produced per plant (Table 4). 'Nkansah' produced the highest number of fruits per plant (27) followed by 'King 5' (13). There were significant differences ($P < 0.001$) for fruit yield per plant among the 19 cultivars. The fruit yield per plant ranged from 26.7 to 571.8g. 'Nkansah' had the highest fruit yield per plant (571.8 g) followed by DV2962 (316.9 g). The weight per fruit differed significantly ($P < 0.001$) among

Table 3. Number of days to flowering, total number of trusses per plant, number of flowers per truss and total number of flowers.

Cultivar	Number of days to first anthesis	Total number of trusses	Number of flowers per truss	Total number of flowers
1 Petomech	29	6	4	17
2 Rio Grande VF	31	4	4	15
3 Tomato rockstone VF	27	6	4	15
4 Caracoli	26	5	5	19
5 F1 Ninja	25	5	4	15
6 Tropimech	23	9	5	19
7 Petomech VF II improved	27	6	5	21
8 Moneymaker	23	5	6	23
9 King 5	24	9	5	20
10 Queen	24	6	4	15
11 18I	24	8	4	17
12 14IR	26	6	4	18
13 8S	24	6	5	18
14 5C	24	5	4	16
15 17 I	22	7	5	20
16 Nkansah	11	14	7	30
17 DV-2962	26	7	5	19
18 Champion	25	6	4	20
19 Wosowoso	22	7	4	17
Mean	24*	7*	5*	19*
LSD ($P<0.05$)	3	2	1	3

*$P<0.001$.

the cultivars. 'Nkansah', which had the highest fruit yield per plant, produced the smallest fruit (25.2 g). 'Queen', 'DV 2962' and 'Wosowoso' had the largest fruits: 93.6, 82.3 and 81.2 g, respectively. 'DV 2962' and 'Wosowoso' were however not significantly different ($P>0.05$) from each other.

The correlations among traits are given in Table 5. Flower drop was positively and moderately

Table 4. Percentage flower drop, number of fruit per plant, total fruit yield per plant (g) and weight per fruit (g).

Cultivar	Percentage flower drop	Number of fruit per plant	Total fruit yield per plant (g)	Weight per fruit (g)
1 Petomech	66.2	3	128.5	67.4
2 Rio Grande VF	69.8	5	134.6	53.7
3 Tomato Rockstone VF	80.5	2	132.9	71.1
4 Caracoli	51.4	3	189.3	75.1
5 F1 Ninja	72.9	1	44.4	44.4
6 Tropimech	63.3	5	171.2	60.3
7 Petomech VF II Improved	42.4	6	203.9	73.3
8 Moneymaker	32.4	4	159.2	52.9
9 King 5	46.9	13	379.8	36.8
10 Queen	58.2	4	202.9	93.6
11 18I CLN 2318 F	57.4	6	322.7	76.4
12 14IR Island Red	58.1	2	146.1	54.5
13 8S Selected SM 1	35.5	3	71.1	38.9
14 5C Roma	61.4	1	26.7	26.0
15 17I CLN 2443 B	74.7	5	186.5	45.2
16 Nkansah	13.6	27	571.8	25.2
17 DV-2962	41.8	7	316.9	82.3
18 Champion	67.1	2	120.9	60.4
19 Wosowoso	79.8	2	99.9	81.2
Mean	56.5**	5**	189.9**	58.9*
LSD ($P<0.05$)	13.9	3	69.5	7.8

*$P<0.05$; **$P<0.01$.

Table 5. Correlation coefficient (r) among variables.

	DtFL	NFR/P	NT	NFL/T	FRY/P	TOTFL	FLD	Wt/F
DtFL	1							
NFR/P	−0.79***	1						
NT	−0.85***	0.89***	1					
NFL/T	−0.77***	0.74***	0.63**	1				
FRY/P	−0.69**	0.92***	0.85***	0.63**	1			
TOTFL	−0.80***	0.80***	0.72**	0.92***	0.69**	1		
FLD	0.33 ns	−0.47***	−0.33***	−0.63**	−0.54*	−0.53*	1	
Wt/ F	0.51*	−0.48 ns	0.42 ns	−0.49*	0.20 ns	−0.49*	0.22**	1

*$P<0.05$, **$P<0.01$, ***$P<0.001$, ns, not significant; DtFL, number of days to flowering; NFR/P, number of fruits per plant; NT, number of trusses; NFL/T, number of flowers per truss; FRY/P, fruit yield per plant; TOTFL, total number of flowers; FLD, flower drop; Wt/F, weight per fruit.

correlated with number of days to flowering ($r=0.33$, $P<0.001$), and weight per fruit ($r=0.22$, $P<0.01$). Flower drop was however negatively correlated to number of fruits ($r=-0.47$, $P<0.001$) and fruit yield per plant ($r=-0.54$, $P<0.001$). Days to flowering were negatively correlated to number of fruits per plant ($r=-0.79$, $P<0.001$), fruit yield per plant ($r=-0.69$, $P<0.01$), number of trusses per plant ($r=-0.85$, $P<0.001$) and total number of flowers ($r=-0.80$, $P<0.001$). Number of fruits per plant was positively and strongly correlated to fruit yield per plant ($r=0.92$, $P<0.001$), number of trusses per plant ($r=0.89$, $P<0.001$) as well as number of flowers per truss and total number of flowers.

PC analysis was done to identify the important reproductive traits that determine the yield of the 19 tomato genotypes. The first two PCs accounted for 79.7% of total variation (Table 6). The first PC explained 68% of the total variation among the genotypes and had positive weights for number of flowers per truss, number of fruits per plant, total number of flowers, yield per plant and number of trusses (Table 6). Among these traits, the most important for PC1 were number of flowers per truss and number of fruits per plant. PC2 explained 11% of the total variability among genotypes and had positive weights for all traits except number of days to flowering and weight per fruit (Table 6). Among these traits, the most important for PC2 was total number of flowers dropped. Number of days to flowering had a high negative weight for PC1 and PC2 (Table 6). This trait also showed significant but negative correlations to number of flowers, number of trusses, number of fruits and fruit yield per plant (Table 6). The PC scores of genotypes were plotted with respect to PC1 and PC2 to assess the genotypic differences (Figure 1). Great variations exist between tomato genotypes. Based on PC analysis, the genotypes with high performance under heat stress were 'Nkansah', 'King 5', '18I' and 'Tropimech', which showed both positive PC1 and PC2 scores. 'Nkansah' had by far the highest positive PC1 score and obtained the largest number of flowers per truss, number of fruits per plant and total number of flowers. The following genotypes recorded positive PC1 and negative PC2: 'DV2962', '8S' and 'Money Maker'.

Table 6. Characteristics of 19 tomato genotypes used in the PC analysis and the Eigen vector of each character on the first two PCs.

	Eigen vectors	
	PCA1	PCA2
Number of days to flowering	**−0.329**	**−0.325**
Number of trusses	**0.351**	**0.358**
Total number of flowers	**0.374**	0.058
Percentage flower drop	**−0.338**	**0.509**
Number of fruits per plant	**0.378**	0.123
Total fruit yield per plant	**0.351**	0.060
Weight per fruit	−0.177	−0.148
Number of flowers per truss	**0.379**	0.022
Variability (%)	68.145	11.604
Cumulative (%)	68.145	79.749

Note: Bold values represent parameters important for PCA1 or PCA2.

Discussion

There was variability observed for most of the traits. Early anthesis was noted in 'Nkansah'. Early anthesis in a cultivar at high temperatures can be considered a good character for adaptation to heat stress, as it enables the crop to produce fruits earlier. There was also a strong correlation found between days to flowering and fruit yield per plant. Delays in flowering can lead to delays in fruit production (Lohar & Peat 1998).

Variability was observed in tomato genotypes for flower drop. Most of the genotypes succumbed to the heat and dropped a large number of their flowers. 'Petomech' and 'Tropimech' are two of the most popular exotic cultivars grown in Ghana during the main season (Monney et al. 2009; Robinson &

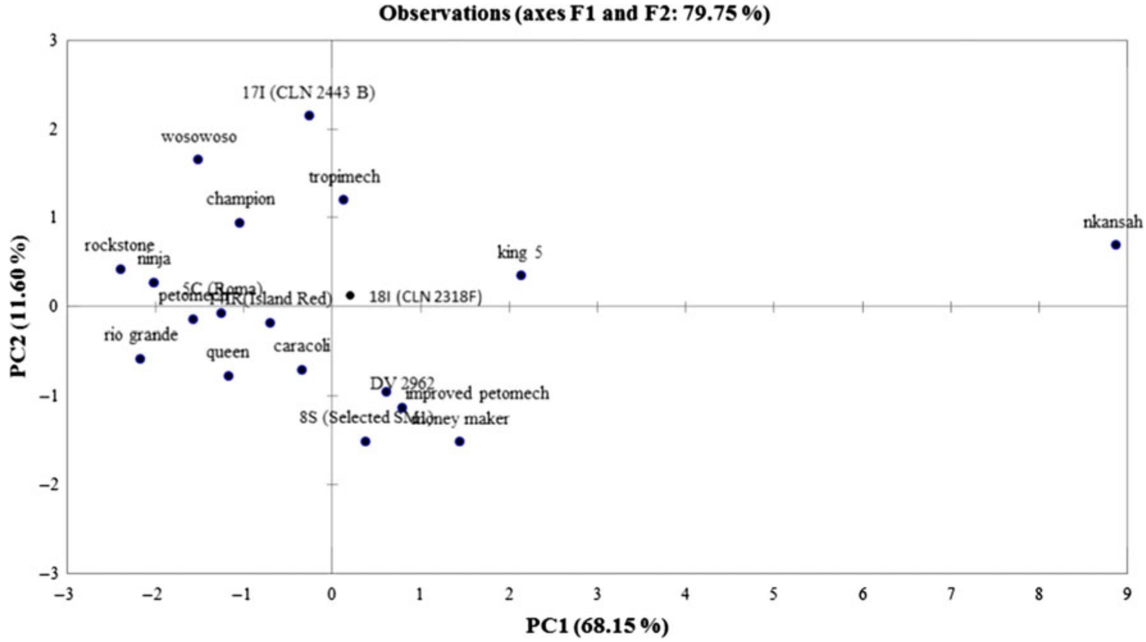

Figure 1. Interspecific differences in tomato genotypes as given by the first two PCs.

Kolavalli 2010). Flower drop was more than 60% among these cultivars. Farmers complain about poor performance of exotic cultivars when grown outside the normal tomato season. 'Nkansah' retained the highest number of flowers and the highest number of fruits. Saeed et al. (2007) observed that genotypes that retained most of their flowers under high temperatures had high fruit yield and concluded that such genotypes could be regarded as 'heat tolerant'. 'Nkansah' may therefore be a cultivar with enhanced adaptation to heat stress. 'Nkansah' however had the smallest fruits, which seems to be a trait of tomato genotypes showing adaptation to heat stress (Nkansah & Ito 1994).

High day and night average temperatures (33.8°C and 25.9°C, respectively) prevailed especially during the early reproductive stage of plant growth. These can cause heat injuries such as low tomato fruit number, low fruit weight, poor fruit set and low yield (Lin et al. 2006). The significant lowest mean values for fruit yield per plant were found in '5C (Roma)' (26.7 g per plant) followed by F_1 Ninja, Selected SM 1 and Wosowoso, respectively. This result indicated that these cultivars were more sensitive to heat stress since they recorded the least yield under stress. On the other hand, the significant highest mean value for yield per plant was reported in 'Nkansah', 'King 5', '18I (CLN 2318 F)' and 'DV 2962' cultivars, indicating that they may be better adapted to heat stress. The other 11 cultivars ('Improved Petomech', 'Queen', 'Caracoli', '17 I (CLN 2443B)', 'Tropimech', 'Moneymaker', '14IR Island Red', 'Rio Grande', 'Tomato Rockstone VF', 'Petomech' and 'Champion') showed intermediate values and therefore, they may be regarded as moderately adapted to heat stress.

Our study found a negative correlation between flowers drop and the number of fruit yield per plant. These findings are consistent with that of Saeed et al. (2007) who indicated decrease in fruit yield with the increased number of flowers shed during heat period. There was no correlation between fruit weight and fruit yield in this study in contrast to Lin et al. (2006), who found a positive correlation between fruit weight and yield and suggested that fruit number and fruit weight may be used as indicators for fruit yield. Increased fruit yield could therefore be obtained by breeding genotypes that were high in fruit number or in fruit weight, but the findings of our study only support the former. Fruit size appears to be genetically stable and not related to total yield. Fruit yield may be related to flower production and increased flower retention as seen by the positive correlation between fruit yield and number of flowers and negative correlation to flower drop; so improving flower retention may be an important breeding target to increase fruit production and thereby fruit yield.

The PC analysis identified the important traits that contribute to fruit yield. PC1 and PC 2 accounted for 68.2 and 11.6 of total variance observed, respectively (Table 6). The Eigen vectors indicated that important traits integrated by PC1 were yield traits including number of flowers per truss, number of flowers per plant, number of fruits per plant, yield per plant, suggesting that

PC1 provided a measure of flower and fruit production. It is worth noting that days to flowering and flower drop had considerably high negative weight for PC1 (Table 6) indicating that a cultivar that flowers early and retains a higher number of flowers tends to produce higher yield in terms of fruit number and fruit yield per plant. The traits important for PC2 are flower drop and number of trusses. Days to flowering also had a high negative weight for PC2.

By plotting a graph of PC1 against PC2 scores, clear differences among the cultivars for different traits related to heat adaptation were visualised. Proceeding from negative to positive values of PC1, number of flowers per truss, number of flowers per plant, number of fruits per plant, yield per plant, number of fruits per plant while on the *y*-axis flower drop and number of trusses increased. 'Nkansah', 'King 5', '18 I (CLN 2318F)' and 'Tropimech' had positive values of PC1 and PC2. Table 4 shows that 'Nkansah' and 'King 5' produced significantly high number of fruits and fruit yield. While '17I (CLN 2443B)', 'Wosowoso', 'Champion', 'Rockstone' and 'Ninja' had negative PC1 and positive PC 2 values. 'Wosowoso' and 'Champion' are local cultivars which have been developed in Ghana.

In summary, our study revealed that a wide variation for adaptation to heat stress exists in tomato for the characters studied. The cultivar 'Nkansah' retained most of its flowers compared with the rest of the genotypes. Based on the fruit yield per plant, and as indicated by the PC analysis, 'Nkansah' could be regarded as a cultivar with enhanced adaptation to heat. It may be used by tomato breeding programmes for improving cultivars with enhanced adaption to heat. Such germplasm can be grown outside the normal season. The commercial hybrid cultivars 'DV2962' and 'King 5' can be also grown during the off-season and still yield substantially well.

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