Pollen, Fruit Yield and Fruit Quality Performances of Heat Tolerant Tomato Varieties to sustain production in West Africa

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Abstract

Tomato production in tropical areas presents a major challenge due to seasonal high temperature stress which can lead to excessive flower drop and low yields. Thus, making available heat tolerant (HT) varieties a major priority to sustain tomato production now and in the future. There are however varying reports of performance of HT tomato varieties especially those grown under different agroecological areas other than the ones where they were developed. It is therefore important to test the performance of these varieties before they are introduced into new areas. A pot experiment was conducted to test nine HT tomato varieties for yield, pollen traits and fruit quality under moderately elevated temperatures. Data was collected on flower, pollen and yield traits, fruit quality traits including pH and Total soluble solids (TSS). Results show that there were significant ($P < 0.05$) differences among tomato varieties for flower number, flower drop, fruitset and fruit yield. Number of fruits per plant ranged from 3 in '*Topgun*' to 18 in '*Supremo*'. Fruit yield was highest in '*Solarfire*' ($P<0.05$) (1311.3 g/plant) and lowest in '*Picus*' (273.1 g/plant). Although on average, non-viable pollen was more than six times that of viable pollen, there was no significant differences among tomato varieties for non-viable pollen and viable pollen. Fruit quality varied significantly among HT tomato varieties. A high TSS, and pH suggest a higher level of "sweetness" in '*Sioux*' '*Supremo*' and '*Picus*' compared to '*Solarfire*' and '*Heatmaster*'. In conclusion the project determined that yield and agronomic performances of the nine HT varieties is generally good however further testing under prevailing field conditions during both main and off-season is important before recommending them for farmers in Ghana.

Keywords: viable pollen, non-viable pollen, fruit set, flower drop, fruit size, pH, TSS, TTA

Introduction

Tomato is an economically important vegetable grown in the world in terms of production, trade and consumption (FAOSTAT, 2017). It is grown under diverse agro environmental conditions, ranging from temperate to hot and humid tropical regions. Under tropical and subtropical conditions, it is grown predominantly under open field rain fed cropping systems (Nicola and Tibaldi, 2009). Unfavorably high temperatures limits productions in these areas which means farmers can only produce the crop during certain times of the year to coincide with optimum growing conditions. Production is therefore highly seasonal further limiting output levels.

The optimum range for tomato is between 18 – 28°C (Saeed *et al.*, 2007). Higher temperatures cause excessive flower drop as well as morphological irregularities such as style exsertion and antheridial cone split, which are mechanical barriers to self-pollination (Saeed *et al.*, 2007). Additionally, pollen production, viability and germination are reduced as a result of alterations in

the metabolism of carbohydrate in the anther during development (Pressman *et al.*, 2002). Therefore, making available HT varieties, presents a long-lasting solution to the disruptive effect of high temperature stress on tomato yields and extend production into the hot seasons, to sustain all year-round cultivation and increase overall yields in many of these areas. In addition, HT tomato varieties may be important in sustaining production under future extreme heat stress conditions predicted under climate change (Silva *et al.*, 2021).

Significant strides have been made in recent times to develop HT varieties. There are several commercial HT tomato varieties found in Asia and Northern America (Scott *et al.*, 2006) which are capable of setting fruit under high temperature and have made significant impact on tomato production in the above mentioned areas. For instance, '*Solarfire*' is an important HT variety which was released in Florida and is capable of setting fruit under moderate high temperature stress (Scott *et al.*, 2006).

HT tomato varieties have yet to be developed in the Sub-Saharan Africa (SSA). This means we may have to rely on HT tomato varieties which have been bred under different agro ecological conditions. Cultivation of HT varieties developed elsewhere have yet to be introduced into SSA and so have made little commercial impact in the region. In addition, although several advances have been made in the development of HT tomatoes, reports still indicate a breakdown of heat tolerance of these varieties especially when grown under different ecological for which they were bred for (de le Peña and Hughes, 2007). Testing new varieties in the area where they are to be introduced is therefore very important before they can be recommended to farmers.

Performance of heat tolerant varieties are mainly evaluated based on their fruit set and fruit yield capabilities under high temperature stress, with recent studies having proposed including pollen traits. Fruit production is a sum total of several other developmental traits including those of flowers, male and female gamete as well as fruit development making this trait a highly unstable, complex one (Paupière *et a*l., 2017). Pollen characteristics has been considered important in determining plant direct responses to high temperatures (Sato *et al.*, 2000). And are linked directly to fruit set and yield under high temperature stress conditions (Paupière *et al.*, 2017; Driedonks *et al.*, 2018)

Heat tolerant varieties have to be first tested before finally being recommended for production under semi-arid tropical conditions of West Africa.

The objective of this study is therefore to:

1. Evaluate commercial HT tomato varieties for flower developmental pattern and yield traits under sustained moderately high temperature stress conditions
2. Determine variability of pollen traits among HT tomato varieties as an indicator of tolerance to heat stress
3. Evaluate fruit quality traits of HT tomatoes under sustained moderately elevated temperature stress

Materials and method

The experiment was carried out at the Soil and Irrigation Research Centre (SIREC), located in the University of Ghana, in Kpong in the Eastern Region of Ghana (latitude 6°09′ N and longitude 00°04′ E). Nine tomato varieties were evaluated (Table1).

Table 1. Sources and description of nine HT tomato varieties used in the study.

No	Tomato cultivar	Origin
1	'Sioux'	Seminis Vegetable Seed, Inc.
2	'Tycoon'	Hazera Seeds Ltd
3	'Phoenix'	Seminis Vegetable Seed, Inc.
4	'Heatmaster'	Seminis Vegetable Seed, Inc
5	'Topgun'	Twilley Seeds Co. Inc.
6	'Heatwave'	Petoseed Co.
7	'Supremo'	Sakata Seed America, Inc.
8	'Picus'	Seminis Vegetable Seed, Inc.
9	'Solarfire'	Harris Moran Seed Company

Environmental conditions in the greenhouse

Seeds were sown on May 23 2017 in seed trays filled with soil (Akuse series) and decomposed poultry manure in a ratio of 1:1 v/v soil to poultry manure. Two seeds were sown in each cell and after emergence, the necessary nursery management was done. Transplanting was done four weeks after planting, into pots filled with 7kg of the same soil to which 1% and 2% by w/w of biochar and poultry manure were added respectively. Akuse series soil used which is a clayey soil classified as a Typic Calcicustert, a Vertisol, deriving from garnetic -Ferrous hornblende gneiss parent material.

There were eight plants assessed for each variety arranged in completely randomised design on a bench in the screenhouse. In total, 72 pots were used. The screenhouse was covered in plastic sheet and maintained moderately high temperatures. Table 2 gives the temperatures during the life span of the experiment. Two weeks after transplanting nutrient in the form of Nitrogen (N) Phosphorus (P) and Potassium (K) (15.15.15) at a rate of 5g /pot. Potassium nitrate (13% N, 46% K) (Multi K™ Classic, Haifa Group) at a rate of 5 g/pot was applied at six weeks after transplanting when plants were at the flowering and early fruiting stage. The insecticide Cydim super (Active Ingredient: 36 g cypermethrin, 400 g dimethoate) were used at the recommended rates to control pest and diseases.

Plants were grown from June 21 (date of transplanting) to October 19 (date of final harvest). Flowering started from July 7 in all the varieties except "*Topgun*" The temperature and humidity were recorded with a mini temperature humidity data logger (Dongguan Xin Rui Instrument Co. Ltd). The average maximum and minimum temperature as well as the humidity during the growth of the nine HT tomato varieties are presented below.

Table 2: Environmental conditions during the growth of nine HT tomato varieties.

Month	May	June	July	August	September	October	Monthly Mean
Max. temp °C	35	32	31	31	32	33	32.2
Min. temp °C	27	25	24	24	25	26	25.2
Relative Humidity %	72	78	81	79	79	78	78

Data was collected on the following key HT traits: flower number as given by total number of flower primordia developed by 56 days after planting (DAP), flower drop and fruit set. Pollen was extracted in previously defined methods (Pressman *et al.*, 2002) before being put into germination solution and dyed with Alexander dye (Alexander, 1980). A drop of solution was mounted on slide and counted under a light microscope. Data was collected on number of viable pollen (stained purple), and non-viable (stained green or non- stained).

Data was also taken on fruit number, i.e. the total number of fruits harvested (only mature, red fruits). Fruit yield as the total fruit weight in grams of each plant using an electric scale. Fruit weight, fruit length, fruit diameter and fruit shape (IPGRI, 1996) of 5 fruits randomly selected were also collected. Five random fruits were selected for data on fruit quality traits which comprise the following : pericarp thickness (the length of widest section on one locule measured with a vernier caliper), fruit pH (juice of cut fruits were squeezed into a beaker and pH determined using a pH meter (Veb Pracitron, Dresden Germany)), total soluble solids (this is an estimate of the amount of sugars in the fruits determined by a refractometer), total titratable acidity, (was determined by the procedure described by (Panthee *et al.*, 2012)) .

Utilizing the GenStat (2009) statistical software the data was subjected to analysis of variance and the differences between means were compared using the least significant difference (LSD). Correlation between parameters were also done.

Results

Variability in flower developmental pattern and yield traits

There was significant difference ($P<0.001$) observed among the nine HT tomato varieties for fruitset and flower drop. The fruitset was low (7.3%) among the tomato varieties. Fruitset was highest in '*Heatmaster*' followed by '*Solarfire*' while the lowest fruitset was recorded in '*Topgun*'. The highest percent of flower drop was observed in '*Picus*' and '*Sioux'* and the least was observed in '*Topgun*', '*Heatwave*' and '*Supremo*'. The percent of others identified as flowers at various stages of development was found to be significantly different ($P<0.001$) among tomato varieties. This trait formed the majority (68%) of the flowering pattern studied. '*Topgun*' had the highest followed by '*Heatwave*' and '*Supremo*'.

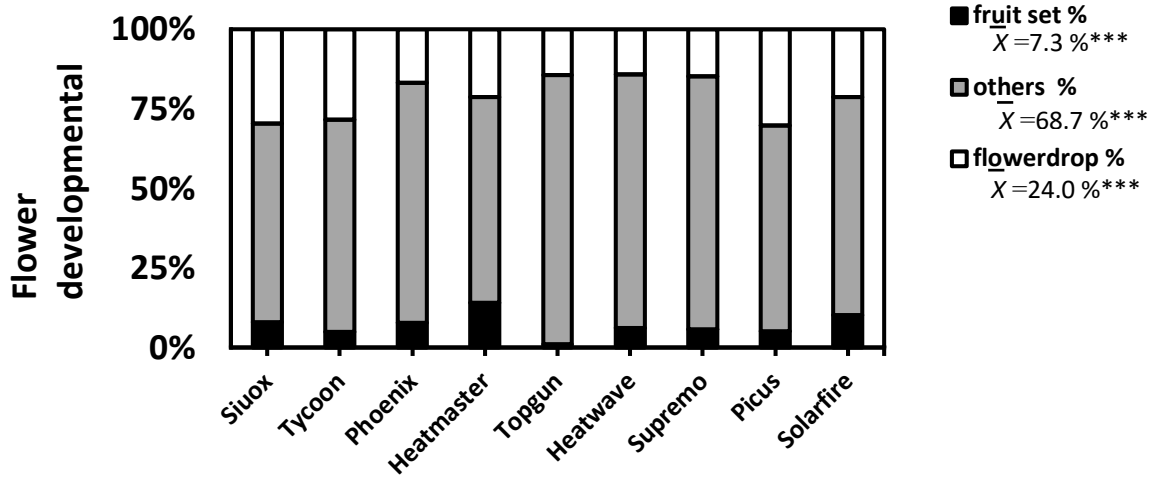

Figure 1: Flower developmental pattern (fruit set, flower drop and others*) of nine HT tomato varieties used in the study. * Flowers at various stages of development

Days to flowering, yield and fruit characteristics are represented in Table 3. There was no significant difference found among the nine tomato varieties for days to flowering. However, '*Topgun*' took the longest (20 days) to flower and the rest took 16 days to flower. Number of fruits per plant varied significantly among the tomato varieties and ranged from 3 in '*Topgun*' to 18 in '*Supremo*'. Average number of fruits per plant was 9 with '*Topgun*', '*Tycoon*' and '*Picus*' having significantly low fruit number. Fruit yield per plant was significantly (P<0.001) higher in '*Solarfire*' compared to the other tomato varieties. Single fruit weight ranged from 49.3g in '*Picus*' to 184.9g in '*Solarfire*' and was found to be significantly different (P<0.001) among tomato varieties. Additionally, '*Phoenix*', '*Supremo*', '*Tycoon*' and '*Topgun*' also had large fruits with weights higher than 100 g. Fruit length and fruit diameter also varied significantly (P<0.001) among tomato varieties.

Table 3: Fruit characteristics of nine tomato varieties grown under high temperature stress

	Variety	Days to flowering	Number fruits / plant	fruit yield/ plant	Single fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Predominant fruit shape
1	Sioux	16	11	572.8	58.8	6.7	8.3	2
2	Tycoon	16	6	531.6	113.2	9.0	10.8	2
3	Phoenix	16	8	802.6 2	123.2	8.7	11.1	1 and 2
4	Heatmaster	16	9	581.5	78.5	7.1	9.2	2
5	Topgun	20	3	311.3	103.8	8.2	11.2	1
6	Heatwave	16	9	700.3 4	92.1	7.4	10.1	2
7	Supremo	16	18	766.8 3	121.5	10.1	9.4	6
8	Picus	16	6	273.1	49.3	8.1	7.3	6
9	Solarfire	16	10	1311.3 1	184.9	10.1	12.1	3
	Mean	16	9^{***}	650.2^{***}	102.8^{***}	8.38^{***}	9.9^{***}	-
	LSD	ns	1	166.4	31.7	1.0	1.28	-

**, *** : Significant at 1% and 0.1% level respectively, ns; not significant

Figure 2 shows the predominant fruit shape. Six out of the nine tomato varieties. '*Sioux*', '*Tycoon*', '*Heatmaster*', '*Heatwave*' and '*Supremo*' had predominantly slightly flattened fruit shape. '*Supremo*' and '*Picus*' were cylindrical (long oblong). Finally, '*Solarfire*' had rounded fruits.

Figure 2. The predominant fruit shaped of some of the HT tomato varieties used in the study

Figure 3 represents the number of non-viable and viable pollen of the tomato HT varieties. Results show that number of non -viable pollen was 80% higher than number of viable pollen in all the tomato varieties. The number of non-viable pollen was not significantly different among tomato varieties. '*Topgun*' had the highest number of non -viable pollen followed by '*Picus*'. It is worth noting that '*Topgun*' which had the least number of fruits per plant produced had the highest number of non-viable pollen among the nine varieties. The least number of non -viable pollen was observed in '*Sioux*'. As in number of non-viable pollen, number of viable-pollen was also not significantly different among tomato varieties.

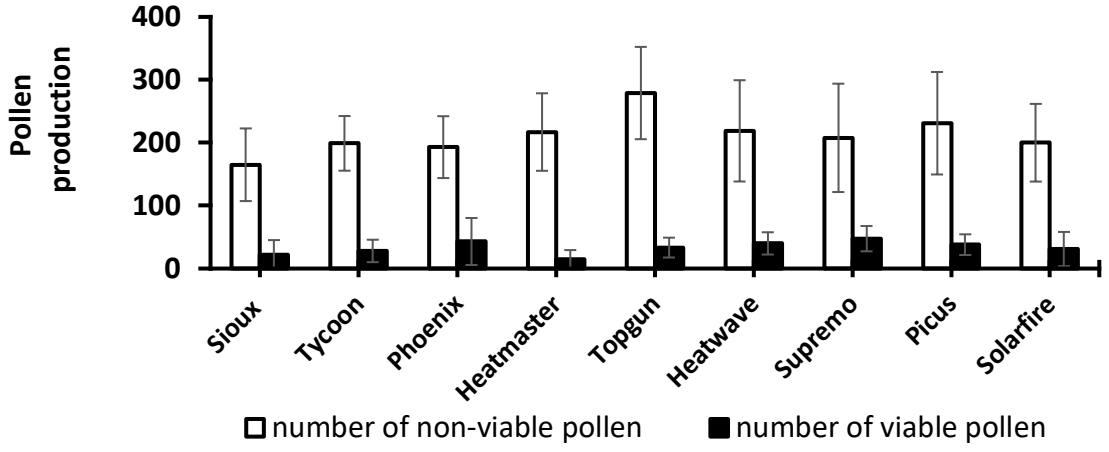

Figure 3: Pollen production consisting number of non-viable pollen and number of viable pollen of nine HT tomato varieties used in the study

Association among reproductive, yield and pollen traits

Days to flowering (DF) had a moderate positive correlation to the number of non-viable pollen (NNVP) (r^2 = 0.36; P<0.05), Percentage Flowers (%F) (r^2 = 0.35; P<0.05) and Total number of pollen (TNP) (r^2 = 0.38; P<0.05) (Table 4). DF showed no correlation to Percentage flower drop %FD (r^2 = - 0.18; ns), %Fruitset (%FS) (r^2 = - 0.33; ns), Fruit yield per plant (FY/P) (r^2 = - 0.25; ns), Number of fruits per plant NF/P (r^2 = - 0.31; ns). Percentage flower drop was however negatively correlated to Percentage fruit set (%FS) (r^2= -0.42; P<0.01), NF/P (r^2=-0.38; P<0.05), %F (r^2=-0.89; P<0.001). Fruit set (FS) was strongly and positively correlated to NF/P ((r^2=0.65; P<0.001). Percentage fruit set (%FS) showed no significant correlation to any of the pollen traits. Predictably, FY/P has a strong positive correlation to NF/P (r^2=0.77; P<0.001), and Single fruit weight (SFW) (r^2=0.36; P<0.05).

Table 4: Correlation and R

	DF	FDt	%FD	%FS	FY/P	NF/P	FL	NNVP	%F	SFW	TNP	NVP
DF	1											
FDt	0.22ns	1										
%FD	-0.18ns	-0.26ns	1									
%FS	-0.33ns	-0.07ns	-0.42**	1								
FY/P	-0.25ns	0.28ns	-0.29ns	0.48ns	1							
NF/P	-0.31ns	-0.05ns	-0.38*	0.65***	0.77***	1						
FL	0.05ns	0.63***	-0.02ns	-0.06ns	0.28ns	-0.15ns	1					
NNVP	0.36*	0.10ns	0.05ns	0.09ns	0.18ns	0.02ns	0.16ns	1				
%F	0.35*	0.32*	-0.89***	-0.04ns	0.08ns	0.09ns	0.05ns	-0.10ns	1			
SFW	0.07ns	0.90***	-0.10ns	-0.03ns	0.36*	-0.09ns	0.79***	0.19ns	0.13ns	1		
TNP	0.38*	0.10ns	0.08ns	0.02ns	0.14ns	-0.05ns	0.20ns	0.94***	-0.10ns	0.18ns	1	
NVP	0.00ns	-0.04ns	0.09ns	-0.20ns	-0.15ns	-0.19ns	0.07ns	-0.34*	0.00ns	-0.05ns	0.02ns	1

*, **, ***: Significant at 5%, 1% and 0.1% level respectively, ns; not significant DF: Days to flowering, FDt: Fruit diameter, %FD: percent flower drop, %FS: percent fruit set, FY/P: Fruit yield/plant, NF/P: Number of fruit /plants, FL: Fruit length, NNVP: Number of non -viable pollen, % O: percent flowers, SFW: Single fruit weight, TNP: total number of pollen, NVP: number of viable pollen.

Variability in fruit quality traits

The tomato variety '*Solarfire*' had significantly more seeds in the fruits whilst the other varieties showed no significant differences in the number of seeds per fruit (Table 5). Fruit pH was significantly lowest in "*Tycoon*" and highest in "*Heatwave*" and '*Picus*'.

Titratable acids were highest in 'Picus' however this was not significantly different from '*Tycoon*' and '*Solarfire*' The mean Brix recorded was 4.78 and varied significantly among the tomato varieties. The variety '*Picus*' which recorded the highest value for pH and titratable acids also had the highest Total Soluble Solids (TSS) reported in ° Brix. However, this was not significantly different from '*Sioux*', '*Tycoon*' and '*Supremo*'. '*Heatmaster*' had the lowest TSS which was comparable to '*Heatwave*' and '*Solarfire*'. Pericarp thickness also varied significantly among tomato varieties. It was significantly highest in '*Heatwave*' which was almost twice the thickness of '*Sioux*' which had the lowest value.

Table 5: Fruit quality characteristics of nine tomato varieties grown under moderately high temperature stress

	variety	No. of seeds/fruit	pH	Titratable Acids (g citric acid/kg tomato)	Total soluble solids ° Brix	Pericarp thickness
1	Sioux	31	4.24	0.86	5.33	3.88
2	Tycoon	24	3.95	0.95	5.07	4.70
3	Phoenix	53	4.37	0.78	4.60	5.40
4	Heatmaster	26	4.10	0.66	3.91	4.51
5	Topgun	-	-	-	-	-
6	Heatwave	27	4.43	0.40	4.35	6.55
7	Supremo	19	4.36	0.74	4.95	5.73
8	Picus	25	4.43	1.14	5.57	4.98
9	Solarfire	119	4.06	0.89	4.45	4.33
	Mean	41***	4.2***	1.25***	4.78**	5.01***
	LSD	31	0.20	0.31	0.82	0.96

, *: Significant at1% and 0.1% level respectively

Discussion

Flower developmental pattern, yield and pollen traits

In West Africa, seasonal high temperatures have been blamed for very low yields of tomato. With the advent of climate change this situation may only worsen as more warmer conditions are predicted in the future (Nicola and Tibaldi, 2009). To sustain production under current and future heat stress conditions, it is of utmost priority to make available HT tomato varieties. However, they must first be tested for adaptability to the new intended area before they are recommended to farmers.

In this study, the average maximum and minimum temperature for the duration of the experiment was 32.2°C and 25.2 °C, respectively. Plants were therefore exposed to a moderately high temperature stress representative of the temperature seen in West Africa. All the tomato varieties flowered early which corresponds with earlier reports (Ayenan *et al.*, 2021; Kugblenu *et al.*, 2013).

Flower drop percent was considerably low for the varieties used and this is consistent with other reports for HT tomato varieties (Kugblenu *et al.*, 2013). However, (Sato *et al.*, 2004) indicated that flower drop in tomato may not a good indicator of improved productivity under heat stress as they observed highest flower drop incidence among tomato varieties identified as heat tolerant. While high fruit set is reported for HT varieties under heat stress, the percentage fruit set was low among the varieties tested in this study compared to what various researchers have reported for normal varieties (Ochar *et al.*, 2019) and especially for HT varieties (Ayenan *et al.*, 2021). The low fruit set in this study therefore indicates a low productivity of these tomato varieties under the prevailing conditions and this was also observed in the low number of fruits per plant. Majority of the varieties had below ten fruits per plant. This is similar to reports by other researchers (Blay *et al.*, 1999 and Ochar *et al.*, 2019).

Fruit yield of HT varieties under stress conditions should be in the range reported under optimal production in the region if farmers are to adopt these varieties and production sustained during the off season. The top three varieties in terms of yield were "*Solarfire*", "*Supremo*" and "*Phoenix*". They will however have to be tested in the field before finally recommending to farmers.

Small fruit size or low single fruit weight are usually reported for HT tomato lines (Lin *et al.*, 2006; Kugblenu *et al.*, 2013) however this was remarkably improved among the HT varieties in this study. For instance, single fruit weight for '*Solarfire*' was comparable to reports by Scott *et al.* (2006) for the same variety. Six out of the nine varieties had single fruit weight larger than 90 g which is comparable higher than what has been reported for many HT and heat sensitive varieties under stress conditions (Kugblenu *et al.*, 2013; Ochar *et al.*, 2019; Ayenan *et al.*, 2021).

In this study, differences observed in fruit yields among tomato varieties was explained by the single fruit weight per plant and number of fruits per plant. As fruit weight and fruit number increased, so did fruit yield. Increase in fruit yield was also linked to percent fruit set and per flower drop. As fruit set increased, the number of fruits per plant increased and consequently the fruit yield as well. In contrast, as the percent flower drop increased, fruit set decreased and consequently number of fruit and fruit yield also decreased.

Pollen traits of HT tomato varieties as an indicator of tolerance to heat stress

Fruit yield and fruit set have been used exclusively to access tomato performance to high temperature stress conditions. Unquestionably so, as the fruit yield is the final goal of researchers. Alternatively, pollen traits have been proposed to determining plant responses under high temperatures (Sato *et al.*, 2000). The study however found no link between fruit yield and pollen traits under moderately high temperature stress (Gonzalo *et al.*, 2020; Ayenan *et al.*, 2021). It was interesting to note that '*Topgun*' reported high values for pollen traits but had reduced fruit yield. Reduce fruit yield in '*Topgun*' was due primarily to its high incidence of the Tomato Yellow Leaf Curl Viral Disease (TYLCVD). From the study it can be inferred that '*Topgun*' may not be limited by heat stress but rather by other environmental factors such as disease incidence and may therefore not be suitable for production in this region due to the high prevalence of this disease in the area.

Fruit quality traits of HT tomatoes under moderately elevated temperature stress

The project found significant differences among the nine tomato varieties for all of the fruit quality traits (pH, TTA, Brix and pericarp thickness) studied, which is to be expected in view of the to the diversity of the tomato varieties used. Fruit quality traits were in the range reported by Blay *et al.*(1999)

A high pH, TA and TSS indicates a higher level of "sweetness" in tomato (Baldwin *et al.*, 2015) suggesting that "*Sioux*" "*Supremo*" and "*Picus*" may be sweeter in taste compared to "*Solarfire*", '*Tycoon*' and '*Heatmaster*', all of which had low values for these traits. The low values recorded for fruit quality traits in "*Solarfire*" was also reported by Baldwin *et al.* (2015). They further reported that the tasting panel they used all indicated low sensory scores in term of sweetness for "*Solarfire*".

Conclusion

The study evaluated nine commercially available HT tomato varieties in a screenhouse under moderately elevated temperatures for their suitability under semi-arid tropical conditions. Fruit set and fruit yield of three varieties were generally good, while the other six had very low fruitset and yield. "*Topgun*" showed high pollen production under moderately high temperature stress, however the yield was limited because of Tomato Yellow Leaf Curl Viral Disease (TYLCVD). The study recommends the following HT tomato varieties for production under moderate heat stress conditions due to their fruiting relatively high fruiting abilities; '*Supremo*', '*Siuox*', '*Solarfire*', '*Phoenix*' and '*Heat wave'*. The study also recommends further testing under open field during extremely high temperatures experienced during the off-season before recommending to farmers in the region.

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