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Research Article

Pollen quality, pollen production and yield of some tomato (*Solanum lycopersicum*) genotypes under high temperature stress in Eastern Mediterranean

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Abstract

Pollen quality, pollen production and yield of different high temperature tolerant tomato genotypes were evaluated under Adana, Turkey conditions in two different periods. The control treatment (normal sown, where day/night temperatures during the vegetative and generative stage are below 32/20 °C) of the first period started on February 20, 2015. The seedlings in the second period were planted on May 15, 2015. The performances of twenty-four tomato genotypes (resistant and sensitive commercial genotypes) were compared to determine high temperature resistant and sensitive tomato genotypes. Significant relationship was obtained between the yield and the number of pollens. The results of the experiment revealed that 'Tom173', 'Tom119' and 'F15656' genotypes were more resistant, while 'Tom108' and 'Tom10' genotypes were more sensitive compared to the other tomato genotypes tested in the experiment.

Keywords: abiotic stress; high temperature; pollen quality; resistance

Introduction

The responses of plants to high temperature stress change depending on plant species and duration of temperature exposure (Driedonks *et al*., 2016; Prasad *et al*., 2017). The generative stage of plants is generally more sensitive to high temperature stress compared to the vegetative stage. Accordingly, germination, pollen viability and pollen production of plants are reduced in response to high temperatures (Xu *et al*., 2017). Zhou *et al*. (2015) indicated that growth and yield of tomatoes are negatively affected by the high temperatures.

The heat temperature stress can be a significant limiting factor for growth, development and production of plants in arid and semi-arid regions. Physiology, biochemical and morphological characteristics of tomato and other plants are significantly affected by the high temperature stress. Seed germination, plant growth, blooming, fruit ripening and several physiological parameters of tomato adversely affected under temperatures over 35 °C. Most of the generative development stages of plants are more sensitive to high temperature stress than vegetative growth stages (Sato *et al*., 2002; Thomas and Prasad, 2003). Previous studies showed that high

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temperature stress restricted to the onset and growth of flower bud; thus, decreased the yields of many crops (Sato *et al*., 2000; Young *et al*., 2004).The high temperature stress during reproductive phase of legumes affects the pollination of flowers, which causes a significant yield loss (Nakano *et al*., 1997; Duthion and Pigeaire, 1991). The increase in temperature to 35 °C in 10 days significantly affected the number of seeds and yield of chickpea (Wang *et al*., 2006). Night temperatures (28 °C) decrease pollen production of peanut (*Arachis hypogaea* L.) and cause yield losses (Prasad *et al*., 1999). The pollens of 'ICC 5912' chickpea genotype showed high susceptibility in exposing to 35 °C during the daytime and 20 °C during the night one day before anthesis. The pollens of 'ICCV 92944' chickpea (*Cicer arietinum* L.) genotype was fertile under optimum temperature at 25 °C daytime and 20 °C night temperatures (Devasirvatham *et al*., 2010), while the pollen viability of four chickpea varieties decreased under 35 °C daytime and 20 °C night temperatures in a growth chamber. In another study, pollen deformities were observed in resistant soybean (*Glycine max* L.) varieties at 38 °C daytime and 30 °C night temperatures (Halterlin *et al*., 1980; Koti *et al*., 2005). Different methods have been used to assess the high temperature resistances of various plant genotypes. Significant differences were reported in tomato seeds under high temperature stress (Sato *et al*., 2002). The use of high temperature resistant plants play an important role in flower development and increase the crop yield. This study was carried out to screen 24 tomato genotypes against high temperature stress and identify temperature stress resistant and sensitive tomato genotypes.

Materials and Methods

The study was carried out at Horticultural Research Fields of Cukurova University in Adana, Turkey. The trial was carried out for two years, and the tomato genotypes used in the current experiment were selected in the first year, as presented by Akhoundnejad and Dasgan (2018). The seeds of tomato genotypes for the control treatment were sown on February 20, 2015. The seedlings were planted to the field in the first week of April (April 7, 2015). This period is considered as normal sown, where day/night temperatures during the vegetative and generative stage are below 32/20 °C. The tomato seeds for the stress test were sown on April 15, 2015, which was determined by examining the long-term temperature values of the region to exposure the vegetative and generative development periods of plants to the high temperature stress. The tomato seedlings were planted to the field on May 15, 2015. The second planting period is considered as late sown, where the temperatures during vegetative and generative stages are above 32/20 °C. The stress test started 38 days after the control treatment. Tomato plants were grouped based on heat stress symptoms (Table 1). Accordingly, the first 20 tomato genotypes were identified as highly resistant, and two genotypes were classified as the most susceptible to heat stress. Two commercial cultivars were used as the control treatment. Selected genotypes and commercial cultivars used in the study were listed in Table 2.

Table 1. Applied weighted rate parameters and multiplying factors in selection

Parameters	Multiplying factor
Normally developed flower pollen	7
The number of anthers in a flower	7
The number of pollens in a flower	9
The number of pollens in an anther	7
Pollen vitality	15
Pollen germination	25
Total Yield	30
Total	100

Table 2. Resistant and sensitive tomato genotypes and commercial cultivars used in the study

No	Resistant genotypes	Genotypes name	No	Resistant genotypes	Genotypes name
1	'Tom-12'	'Rio Grande'	14	'Tom-173'	'TR 52361'
2	'Tom-14'	'Cambell 33'	15	'Tom-201-B'	'Kirkizistan'
3	'Tom-19'	'Roza'	16	'Tom-211'	'Kırgızistan Sarı'
4	'Tom-20'	'1071-33'	17	'Tom-225'	'Cln3126a-7'
5	'Tom-26'	'1009-6'	18	'Tom-230'	'Cln3125o'
6	'Tom-40'	'227/1'	19	'Tom-232'	'Cln3078c'
7	'Tom-47'	'Red Cherry-Large'	20	'Tom-233'	'Cln3078g-Av'
8	'Tom-108'	'Pakmor'		Sensitive genotypes	
9	'Tom-111'	'Tridora. RHT 1'	21	'Tom-175'	'TR 52377'
10	'Tom-114'	'Lignon S5'	22	'Tom-116'	'Lignon S1'
11	'Tom-115'	'Lignon S2'		Commercial variety	
12	'Tom-119'	'Adana Yerli'	23	'Hazera 5656 F1'	'Hazera 5656 F1'
13	'Tom-165'	'TR 62573'	24	'Tom-10'	'H 2274'

The experimental layout was a randomized block with four replicates and 10 seedlings were planted in each replicate. Two blocks, one for yield and one for pollen analysis, were established. Tomato seedlings were planted in 120 cm interrow and 50 cm intra row spacings. The study was carried out under field conditions and seedlings were planted at two different periods. Pollen quality was assessed; pollen production tests were carried out and tomato yield were determined. The pollen analysis was performed 2 times in June 16 and July 20, 2015. The plants were 75 and 95 days old, respectively when the high temperatures started. The temperature and humidity values recorded during the study were shown in Figures 1 and 2.

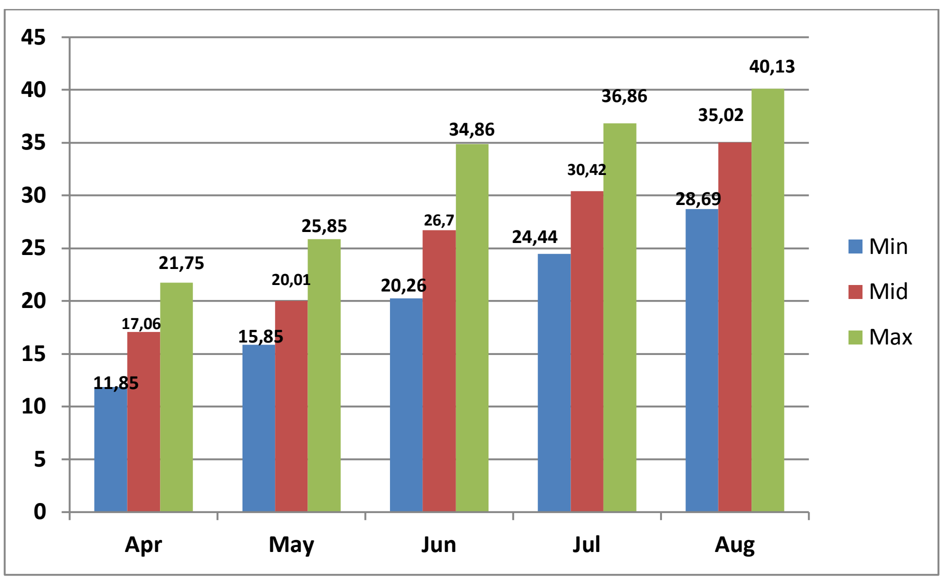

Figure 1. Maximum, minimum and mean temperature values (°C) of the study field in 2015

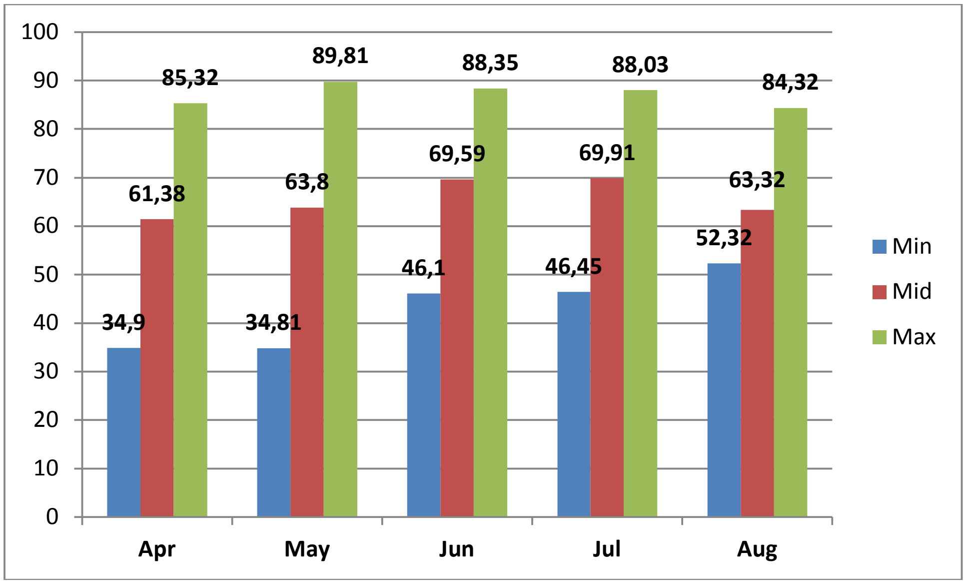

Figure 2. Maximum, minimum and mean relative air humidity values (%) of the study field in 2015

Tomato plants were fertilized according to Akhoundnejad (2011) who modified the recommendations of Gunay (2005). The results of soil analysis for 0-30 cm depth were shown in Table 3. Fertilizers were applied at rates of 160 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1}, 230 kg K_2O ha^{-1}, 100 kg CaO ha^{-1} and 120 kg MgO ha^{-1}.

Table 3. Some of physical and chemical properties of soil samples (0-30 cm)

Soil	Unit	Value
pH	--	8.4
EC	dSm^{-1}	0.013
N	%	0.082
P	kg P_2O_5 ha^{-1}	63
K	kg K_2O ha^{-1}	1123
Ca	kg CaO ha^{-1}	19901
Mg	kg MgO ha^{-1}	2403
Fe	mg kg^{-1}	0.85
Mn	mg kg^{-1}	0.82
Zn	mg kg^{-1}	0.11
Cu	mg kg^{-1}	0.26

The flowers for pollen viability and germination tests were collected one day before collection of anthesis, and the anthers were collected and placed at room temperature to dry and anther dehiscence. Pollens were collected and used in the experiment as described by Eti (1991).

In vitro pollen viability test (%)

Four doses of triphenyltetrazolium chloride (TTC) solution (1, 2, 3 and 5%) was used to determine the pollen viability levels of 24 tomato genotypes. The TTC solution was prepared according to Norton (1966).

In vitro pollen germination test (%)

Pollen germination tests were carried out by using "agar in Petri dish" method. The germination medium containing 1% agar + 12.5% sucrose at 20 °C, which is considered as the optimum medium for tomatoes by Derin (1998) was used in *in vitro* pollen germination tests.

Pollen production

Pollen production of tomato genotypes were determined by using Hemacytometric method described by Eti (1990). For each genotype, the normally developed pollen, the number of anthers per flower, the number of pollens per flower and the number of pollens per anther were determined as described in Eti (1990).

Total crop yield (kg m^{-2})

The weight and the number of tomato fruits harvested at each week during the experiments were recorded, and the total yield was calculated at the end of the season.

Statistical analysis

The experiment was carried out with four replications and 10 tomato plants were grown in each replicate. Experimental design was a randomized block, and the data was analysed using the experimental design by JMP statistical software. Analysis of variance (ANOVA) was conducted to test the significance in the data. Least significant difference (LSD) test at 95% probability was used as post hoc where ANOVA indicated significant differences.

Results

Pollen production

Pollen viability of tomato genotypes under high temperature stress significantly decreased ($p < 0.001$). Mean pollen viability in control and high temperature stress was 61 and 55%, respectively (Table 4), which was indicated a 4.4% decrease under high temperature stress compared to the control treatment. Tomato genotypes resistant to high temperature stress in terms of pollen vitality were 'Tom175' (21.64%), 'Tom 173' (1.04%) and 'Tom14' (58.57%), respectively. Tomato genotypes sensitive to high temperature stress in terms of pollen vitality were 'Tom12' (-41.97%) and 'TomF1 56' (-40.00%).

The mean pollen germination ratio in control and high temperature stress was 15 and 12%, respectively. The decrease in mean pollen germination rate under high temperature stress was 28.98% relative to the control treatment. Tomato genotypes resistant to high temperature stress in terms of pollen germination values were 'Tom19' (61.34%) and 'Tom20' (117.94%), while the tomato genotypes sensitive to high temperature stress were 'Tom14' (-70.00%), 'Tom119' (-73.63%) and 'Tom211' (-63.46%), respectively. The difference in pollen vitality values among the tomato genotypes was statistically significant ($P \leq 0.01$) (Table 4). The parameters investigated indicated the interaction between tomato genotypes and high temperature stress. Normally developed flower pollen, the number of anthers in a flower, the number of pollens in a flower, the number of pollens in an anther and pollen vitality were important for the germination and total yield ($P \leq 0.01$) (Table 8). The highest pollen vitality was obtained for 'Tom173', 'Tom14' and 'F1175', respectively. The high temperature stress had a significant ($P \leq 0.01$) impact on total yield and the highest total yield was recorded for 'Tom173' genotype (Table 7).

Pollen quality

The mean normally developed pollen ratio in control and high temperature stress was 84.98 and 79.98%, respectively. The differences in normally developed pollen ratio between genotypes were statistically important. The resistant tomato genotypes based on normally developed pollen ratio were 'Tom 173' (10.14%), 'Tom115'

(5.19%) and 'Tom201-B' (21.18%), while 'Tom19' (-22.75%) and 'Tom116' (-18.70%) genotypes were sensitive to high temperature stress (Table 5).

Table 4. Pollen vitality and pollen germination responses of tomato genotypes under high temperature stress conditions

	Pollen vitality (%)		Pollen germination (%)	
Genotype	Control	*H.T.S	Control	*H.T.S
'Tom-10'	69 g-h	76 b-d	6.1 d-f	3.8 d-i
'Tom-12'	81 a-e	47 g	7.8 a-e	7.7 ab
'Tom-14'	70 f-h	111 a	10 ab	3.0 e-j
'Tom-19'	62 h	83 c-f	4.4 e-g	7.1 a-d
'Tom-20'	74 d-g	63 c-g	3.9 f-g	8.5 a
'Tom-26'	82 a-d	67 c-g	7.4 a-e	6.1 a-d
'Tom-40'	78 b-g	67 c-g	5.2 d-g	4.0 d-i
'Tom-47'	78 b-g	59 d-g	5.9 c-f	2.4 h-j
'Tom-108'	69 g-h	51 f-g	7.8 a-d	7.9 a
'Tom-111'	74 e-g	79 bc	5.3 f-g	2.9 f-j
'Tom-114'	81 a-e	64 c-g	7.03 a-f	3.4 d-j
'Tom-115'	32 i	65 c-g	8.8 a-d	5.6 a-f
'Tom-116'	72 f-g	65 c-g	9.6 a-c	5.6 a-f
'Tom-119'	85 ab	65 c-g	11 ab	2.9 f-j
'Tom-165'	83 a-d	62 c-g	6.9 a-f	4.2 c-i
'Tom-173'	96 a	97 b	8.01 a-d	5.4 a-h
'Tom-175'	76 c-g	97 c-g	7.4 a-e	4.5 c-i
'Tom-201B'	84 a-c	66 c-g	9.8 a-c	2.6 g-j
'Tom-211'	74 d-g	67 c-f	5.2 d-g	1.9 i-j
'Tom-225'	72 f-h	57 f-g	7.03 a-f	4.8 a-h
'Tom-230'	76 C-g	71 c-f	7.5 a-f	6.0 a-e
'Tom-232'	82 a-e	67 c-g	8.07 a-d	1.5 j
'Tom-233'	83 a-d	74 b-e	2.6 g	2.3 h-j
'F15656'	80 a-f	48 g	10 a-c	7.4a-c
Mean	61	55	15	12
LSD0.05	5.98	12.25	4.32	4.2

H.T.S: High temperature stress.

Table 5. The amount of pollens and the number of anthers in a flower of 24 tomato genotypes in response to high temperature stress

Genotype	Normally developed pollen (%)		Anther per Flower	
	Control	*H.T.S	Control	*H.T.S
'Tom-10'	82.39 d-h	76.57 d-f	5.86 hi	6.16 e-i
'Tom-12'	87.08 b-g	78.43 b-e	5.70 ij	5.80 i-k
'Tom-14'	96.57 a	85.78 a-c	6.76 a-d	7.06 ab
'Tom-19'	74.11 h-i	57.25 g	5.93 g-i	5.86 h-k
'Tom-20'	82.79 d-h	81.74 a-e	6.66 b-e	6.06 b-f
'Tom-26'	82.49 d-h	82.54 a-e	6.06 f-i	6.46 c-g
'Tom-40'	88.67 a-e	77.62 c-f	6.80 a-c	7.00 a-d
'Tom-47'	84.74 b-g	82.15 a-e	5.83 hi	5.23 l
'Tom-108'	78.84 g-h	76.23 d-f	6.20 f-h	6.30 e-i
'Tom-111'	85.52 b-g	69.17 f	7.03 ab	5.90 g-k
'Tom-114'	85.28 b-g	80.31 a-e	6.26 E-h	6.10 f-j
'Tom-115'	79.75 e-h	83.89 a-e	7.06 ab	7.43 a

'Tom-116'	94.01 ab	76.43 d-f	6.40 c-f	6.43 d-h
'Tom-119'	88.88 a-e	87.89 a	7.20 a	6.73 b-e
'Tom-165'	83.69 c-g	80.94 a-e	6.08 f-i	6.93 a-d
'Tom-173'	79.29 f-h	87.33 ab	6.16 f-h	7.06 ab
'Tom-175'	86.67 b-g	80.70 a-e	6.33 d-g	6.20 e-i
'Tom-201B'	66.93 i	81.11 a-e	5.98 f-i	6.16 e-i
'Tom-211'	92.99 a-c	84.95 a-d	6.83 a-c	7.03 a-c
'Tom-225'	88.56 a-f	83.89 a-e	5.33 j	5.40 kl
'Tom-230'	89.80 a-d	86.87 a-b	5.33 j	5.56 j-l
'Tom-232'	87.19 b-g	75.63 e-f	6.10 f-i	5.76 i-l
'Tom-233'	83.28 d-h	80.04 a-e	5.66 ij	5.90 g-k
'F15656'	89.98 a-d	82.07 a-e	7.20 a	7.76 a
Mean	84.98	79.98	6.28	6.35
LSD0.05	9.33	8.91	0.45	0.59

H.T.S: High temperature stress.

Tomato genotypes resistant to high temperature stress in terms of the number of anthers in a flower were 'Tom173' (14.61%) and 'F15656' (7.78%), while sensitive genotypes were 'Tom111' (-16.07%) and 'Tom232' (-5.57%) (Table5). The mean number of pollens in a flower in control and high temperature stress were 1319242 and 10622585 pollen flower-1. The decrease under high temperature stress conditions was 11.3% compared to the control. Tomato genotypes resistant to high temperature stress in terms of the number of pollens in a flower were 'Tom108' (94.32), 'Tom115' (53.08) and 'Tom173' (34.78), respectively. Tomato genotypes sensitive to high temperature stress in terms of the number of pollens in a flower were 'Tom12' (-89.17), 'Hazera F1' (-69.34) and 'Tom225' (-63.62), respectively. The mean flower powders pollen in an antherin control and high temperature stress was 129648 and 174603 number/flower. High temperature stress caused a 38.8% decrease in the mean flower powders in an anther compared to the control treatment. Tomato genotypes resistant to high temperature stress in terms of number of flower powders in an anther were 'Tom108' (190.93) 'Tom 115' (174.88) 'Tom10' (109.20), respectively. Tomato genotypes sensitive to high temperature stress in terms of the number of flower powders in an anther were 'Tom116' (-48.53) and 'Tom230' (-37.46) (Table 6).

Table 6. The number of pollens in a flower and the number of flower powders in an anther in response to high temperature stress for 24 tomato genotypes

	The number of pollen in a flower		The number of flower powders in an anther	
Genotype	Control	*H.T.S	Control	*H.T.S
'Tom-10'	859166 f-h	1007500 f g	78734 fg	164708 f-i
'Tom-12'	1297500 b-e	140500 d e	175080 c	242287 b-d
'Tom-14'	682617 h	742500 g-i	76660 fg	112540 j-m
'Tom-19'	767500 h	1085000 e f	74607 fe	151000 g-k
'Tom-20'	1480833 b-e	731666 g-i	92326 fg	106226 k-m
'Tom-26'	738750 h	751666 f-i	66160 g	105269 k-m
'Tom-40'	1688333 b	850000 f-i	88041 fg	121144 i-m
'Tom-47'	1496666 b-e	991666 f g	129813 de	191679 d-g
'Tom-108'	792500 g h	1540000 b-d	76585 fg	222808 c-e
'Tom-111'	1342500 b-e	521875 i	131630 de	89548 m
'Tom-114'	1264166 d-f	954166 f-h	106253 ef	136159 h-m
'Tom-115'	1272250 c-e	1947500 a	104145 ef	286273 ab
'Tom-116'	1657500 b-d	857500 f-i	273276 a	140665 g-m
'Tom-119'	1437500 b-e	1820833 a b	176242 c	285514 ab
'Tom-165'	1507678 b-e	1570000 b-d	176246 c	228141 c-e

'Tom-173'	1456666 b-e	1963333 a	171163 c	249023 bc
'Tom-175'	1350833 b-e	1360833 de	132837 de	209362 c-f
'Tom-201B'	714950 h	625833 hi	81737 fg	96188 lm
'Tom-211'	1314814 b-e	1803333 ac	136074 de	160707 f-j
'Tom-225'	461775	168000 l	151761 h	316945 a
'Tom-230'	1672708 bc	798333 f-i	225937 b	141297 g-m
'Tom-232'	1193768 e-g	1466666 c-d	153346 cd	176425 e-h
'Tom-233'	2395000 a	940000 f-h	94328 fg	142758 g-l
'F15656'	2815833 a	863333 e-g	138574 d-f	113808 j-m
Mean	1319242	1062585	129648	174603
LSD0.05	2.86	3.41	34397	50929

H.T.S: High temperature stress.

Total yield

The total yield in control and high temperature stress was 5.48 and 4.91 kgm^{-2}, respectively, which correspond to the 9.59% decrease under high temperature stress conditions. Tomato genotypes resistant to high temperature stress in terms of total yield were 'Tom173' (16.7 kg m^{-2}); 'Tom119' (12.5 kg m^{-2}); 'Tom47' (9.3 kg m^{-2}); 'Tom115' (8.7 kg m^{-2}); 'Tom165' (7.1 kg m^{-2}) and F'15656' (7.6 kg m^{-2}). Tomato genotypes sensitive to high temperature stress in terms of the total yield were 'Tom10' (-38.1 kg m^{-2}), 'Tom108' (-26.6 kg m^{-2}) and 'Tom201B' (-24.8 kg m^{-2}), respectively (Table 7).

Table 7. Total fruit yield of 24 tomato genotypes in response high temperature stress

Genotype	Control (kgm^{-2})	High temperature stress (kgm^{-2})
'Tom-10'	5.98 a-c	3.70 I
'Tom-12'	5.89 a-d	4.51 f-h
'Tom-14'	5.42 b-e	5.21 c-f
'Tom-19'	5.40 b-f	5.48 d-f
'Tom-20'	4.85 e-h	3.45 I
'Tom-26'	5.98 a-c	5.14 d-f
'Tom-40'	5.93 a-c	4.97 e-f
'Tom-47'	5.70 a-e	6.23 ab
'Tom-108'	6.44 a	4.73 e-g
'Tom-111'	6.25 a-b	6.56 a
'Tom-114'	5.26 c-g	4.75 e-g
'Tom-115'	5.30 c-g	5.76 b-d
'Tom-116'	4.48 f-ı	3.67 I
'Tom-119'	4.01 h-ı	4.51 f-h
'Tom-165'	4.95 d-h	5.30 c-e
'Tom-173'	3.59 ı	4.19 g-I
'Tom-175'	4.93 e-h	3.77 hi
'Tom-201B'	6.60 a	4.96 ef
'Tom-211'	4.39 g-ı	4.16 g-I
'Tom-225'	5.33 b-g	4.71 e-g
'Tom-230'	5.49 b-e	4.17 g-I
'Tom-232'	6.63 a	5.83 a-d
'Tom-233'	6.60 a	5.88 a-c
'F15656'	6.04 a-c	6.50 ab
Mean	5.48	4.91
LSD0.05	0.93	0.74

Discussion

The results of the study revealed that pollen viability decreased under high temperature stress. The decrease in pollen viability was greater in 'Tom108', 'Tom115' and 'Tom173' genotypes. Çuruk and Abak (1992) who conducted a study on the effects of moisture and high temperature on flower dust vitality and germination ability of some tomato varieties, indicated a decrease in the viability of flower dust as the temperature increased. Like the viability of the flower dusts the germination ability of flower powders in most genotypes had also a significant decrease with the increase in temperature. The parameters of some plants have great plasticity, which is called the syndrome stage. Yamori *et al*. (2014) reported a significant decrease in the pollen viability at high temperature, whereas they did not indicate any effect on yield. The decrease in pollen viability of tomato plants was attributed the low sugar content of pollen grains in the development stage. Daşgan *et al*. (1993) investigated the viability and germination power of tomato flower powders, and their relationships with the yield in two plastic greenhouses. The minimum temperature of the first greenhouse was adjusted to 13 °C and 5 °C, and the mean temperature in the second greenhouse was 13.9 °C and 10.1 °C throughout the season. Ercan *et al*. (1994) studied the germination rate of tomato, pepper and eggplant, which are the members of Solanaceae family in two different periods. The germination rates at the beginning flowering period were 74% for eggplant, 65% for pepper and 68% for tomato. The increasing temperatures in the second half of July caused decreasing the germination rates to 60% for eggplants and peppers and to 30% for tomatoes. Abnormal pollen formation was also increased in species with low germination rate. The decrease in fruit set between the first period (until the end of June) and the second period (from the beginning of July to the end of the production period) was 5.5% in eggplant, 6.4% in pepper and 12.3%. Ravestijin *et al*. (1969) determined the germination status the flower powders of strawberry, pepper and tomato species at different temperatures (10, 17, 31 and 38 °C) and atmospheric humidity between 50 and 70%. The best germination rate (94%) was recorded for tomato at 17 °C, and the mean germination rate at other temperatures was 88%. The germination rate decreased with increasing the temperature, and the lowest rate (30%) was recorded at 38 °C. The mean flower dust germination rate of peppers and strawberries at 20 °C was reported as 97%. Takagaki *et al*. (1995) indicated that 8 hours application of 33 °C temperature had a slight impact on the efficiency and germination of flower dusts in three species, while 38 °C temperature caused large decline on the efficiency and germination of flower dusts. In this study, abnormalities in pollen morphology were not observed in high temperature stress. The results can be attributed to the high temperature stress exposure period. In our study, high temperatures were occurred during the anthesis stage, while abnormalities in pollen morphology occurs in high temperatures during pollen development. High temperatures (>35 °C) during the pollination and fertilization stages decreased the viability of pollen sin the maize plants (Dupuis and Dumas, 1990). Arfan *et al*. (2018) reported that the increase in seed cotton yield of 'FH-114' × 'KZ-191' cotton lines over better parent under normal and heat stress conditions were 22.61 and 30.19%, respectively. 'Tom119' and 'Tom173' genotypes were determined as resistant to high temperature stress in terms of total yield. Similarly, 'Tom19' and 'Tom20' genotypes were considered resistant in terms of pollen germination rate and 'Tom175', 'Tom173' and 'Tom14' tomato genotypes were resistant for the pollen production. The results revealed that productivity increases with increase in the germination rate. In addition, yield was determined to be the most sensitive parameters affected by the high temperature stress. The results indicated that 'Tom10', and 'Tom 20' genotypes were resistant in terms of total yield, and 'Tom14' and 'Tom119' were resistant for the pollen germination. The genotype 'Tom12' was considered sensitive in terms of pollen production test. The duration of temperature, in addition to different temperature stress and humidity, needs to be included to the future studies on pollen germination in tomato. Abak *et al*. (1996) investigated the cultivation of pollen production and the effects of pollination with bumblebee on the quality of pepper fruits grown in the winter season under different temperatures. Prasad *et al*. (2006) investigated the effects of high temperatures on the rice harvest index. High temperatures caused significant decreases in the harvest indexes of 14 different rice varieties. The findings of Adams *et al*. (2001) are also in accordance with many others, and they reported that high temperature decreased the tomato yield. Linda (1992) screened high temperature resistant tomato genotypes in two different region and reported that yield decrease was higher at higher temperatures. High temperature stress reported preventing the opening of anthers and absorption of endosperm in quinoa plants; therefore, the pollen production of quinoa plants was decreased at high temperatures (Peterson and Murphy, 2015). Zhang and Xu (2008) investigated the effect of high temperature on photosynthesis and tomato yield, and reported significant decreases in photosynthesis as well as the yield under high temperatures. High temperature has been reported affecting the breeding time, pollen vitality, fertilization and the fruit behavior (Hatfield *et al*., 2008, 2011). High temperature efficiency in physiological properties can be assessed to improve the selection efficiency of crops (Wasif *et al*., 2019). The pointing of parameters measured in different tomato genotypes under high temperature stress have been shown from the highest to the lowest point (Table 9).

Table 8. The results of analysis of variance for pollen quality, pollen production and yield of tomato genotypes

Analysis of variance	Normally developed flower pollen	Number of anthers in a flower	Number of pollens in a flower	Number of pollens in an anther	Pollen vitality	Pollen germination	Total Yield
Stress(S)	**	**	**	**	**	**	**
Genotypes(G)	**	**	**	**	**	**	**
S*G	**	**	**	**	**	**	**

** indicate the level of significance at p≤0.01.

Table 9. The rankings of 24 tomato genotypes from the highest to the lowest point

Tomato genotypes	Pointing parameters
'Tom-173'	6247.37
'Tom-119'	3408.1
'F15656'	1908.42
'Tom-47'	1214.56
'Tom-115'	1142.49
'Tom-26'	-657.46
'Tom-165'	-826.67
'Tom-175'	-922.95
'Tom-233'	-963.02
'Tom-19'	-1461.85
'Tom-211'	-1463.39
'Tom-40'	-1524.79
'Tom-201B'	-1826.93
'Tom-14'	-1860.53
'Tom-111'	-1900.89
'Tom-12'	-1954.76
'Tom-114'	-1979.21
'Tom-230'	-2043.93
'Tom-20'	-2326.25
'Tom-232'	-2493.32
'Tom-225'	-2607.45
'Tom-116'	-2632.3
'Tom-108'	-3433.4
'Tom-10'	-3578.56

Conclusions

The results of the study indicated that yield, pollen germination and the amount of pollen production are important parameters to determine the resistant for tomato genotypes to the highest temperature stress. Future breeding and F1 line improvement studies should start with the development of high temperature stress resistant genotypes. The most resistant tomato genotypes need to be chosen due the global climate change and the temperature increase. The results revealed that the prominent tomato genotypes determined in this study could be recommended for the hot regions.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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