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G × E interaction and heterosis in elite tomato hybrids for growth, earliness and fruit parameters in diverse agro-climatic zones of Punjab

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ABSTRACT

Six promising tomato hybrids selected from a pool of 60 F_1 hybrids were evaluated for seven traits, along with the check hybrid (TH-1) at two locations falling under different agro-climatic zones of Punjab, India. G × E interaction was significant for early yield, fruit weight and total fruit yield, whereas, it was non-significant for fruit number, locule number, pericarp thickness and vine length. Overall higher mean-early-yield, fruit number, fruit weight and total yield at Ludhiana, rather than at Bathinda, may be due to higher organic carbon, available phosphorus and available potash and low electrical conductivity of the experimental soil at Ludhiana. Pooled analysis showed that hybrid TH-21 had the maximum early-yield (3.73 tha^{-1}), fruit weight (72.7 g) and locule number (2.65), whereas, TH-23 had the highest fruit number per vine (53.7) and total fruit yield (51.2 tha^{-1}). The magnitude of pooled standard heterosis was maximum for vine length (140.7%), followed by early yield (114.8%), total yield (88.3%), fruit number (49.7%), fruit weight (27.6%), pericarp thickness (16.4%) and locule number (-21.6%). On the basis of stability and superiority for fruit weight, fruit number, early and total yield, TH-21 was found to be the most promising hybrid, followed by TH-23.

Key words: Fruit number, fruit weight, hybrid, stability, tomato, yield

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops of Punjab, cultivated over 7,580 hectare in 2014-15 and produced 1,85,900 metric tonnes with average productivity of 24.525 metric tonnes ha^{-1} (Anon., 2015). At the national level, productivity of tomato has increased from 15.74 metric tonnes ha^{-1} in the year 2001 to 19.45 metric tonnes ha^{-1} in 2011 (Anon., 2014). This substantial increment is partly due to availability and adoption of high-yielding tomato hybrids in the country. Tomato hybrids are very popular among farmers because of earliness, high yield, uniformity of the produce and higher adaptability to unfavorable environment (Yordanov, 1983). The high cost of hybrid seeds is not an obstacle in their popularity as it is compensated by the realized higher profits obtained from their cultivation (Cheema and Dhaliwal, 2005). Three F_1 hybrids of tomato, viz. TH-2312, TH-802 and TH-1, have thus far been released for commercial cultivation at the State level the Punjab Agricultural University. The last hybrid, i.e. TH-1, was released in the year 2003 (Singh *et al*, 2004). Before recommending any hybrid for commercial cultivation, its evaluation in diverse agro-climatic locations is very important owing to the genotype × environment interactions due to variations in soil fertility, irrigation-water quality and other agro-climatic conditions prevalent at different zones. Genetic stability (homeostasis) in the hybrids refers to reduced genotype × environment interaction. A majority of quantitative traits are significantly affected by environmental factors, and, heterosis too is dependent on environment. Therefore, evaluation of a given tomato hybrid, when grown at different locations, is necessary for obtaining reliable information on its overall performance. This kind of information is of great importance to tomato breeders, as, it can help them make intelligent decisions

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on cultivar selection (Atanassova and Georgiev, 2007). Therefore, the present study was conducted to estimate G × E interaction among seven promising tomato F_1 hybrids, and, to ascertain the magnitude and direction of heterosis over a standard Check hybrid for plant growth, yield and fruit parameters two, in diverse agro-climatic zones of Punjab.

MATERIAL AND METHODS

Six promising F_1 hybrids of tomato were selected for multi-location testing from a pool of 60 hybrids evaluated at Ludhiana for two years. These six elite hybrids, along with one standard Check hybrid,i.e. TH-1, were evaluated in a Randomized Complete Block Design (RCBD), with three replications, at two diverse locations falling under different agro-climatic regions of Punjab, i.e. Vegetable Research Farm, Punjab Agricultural University, Ludhiana (E_1) (30° 54' N latitude, 75° 48' E longitude, 247 amsl altitude) and Jodhpur Romana Farm, Regional Research Station, Punjab Agricultural University, Bathinda (E_2) (30° 9' 36" N latitude, 74° 55' 28" E longitude, 211 amsl altitude) during October 2010 to May 2011. Seeds were sown in well-prepared nursery beds in end-October, 2010. Seedlings were transplanted on the southern side of the beds prepared in East-West direction at a spacing of 1.20 m × 0.30 m, in end-November, 2010. Ten plants from each entry were transplanted in single row in each replication. Recommended cultural and plant-protection measures were followed for raising the crop (Anon., 2013). Irrigation was applied needed and at regular intervals at Ludhiana; however, at Bathinda, irrigation was not applied for three weeks in April, though needed by the crop, due to non-availability of good quality canal water (the tube-well water-being saline-sodic, was not used for irrigation purpose). Mean monthly agro-meteorological recorded during the crop season at both the locations are presented in Table 1. Characteristics of the experimental soil (0-15 cm soil profile) at the two locations are presented in Table 2.

Observations were recorded for seven characters, viz., early yield (t ha^{-1}), fruit number per vine, fruit weight (g), locule number, pericarp thickness (mm), vine length (cm) and total fruit yield (t ha^{-1}). A total of five pickings were made from mid-April to end-May. Yield obtained in the first picking was treated as 'early yield'. Average weight of ten randomly-chosen fruits from the second, third and fourth pickings was used for estimating fruit weight. Locule number and pericarp thickness were estimated from ten randomly-selected fruits from the third picking. Vine length was recorded after the final picking on five randomly-chosen, competitive plants. Data were analyzed for analysis of variance (ANOVA) using the computer software programme CPCS1. Heterosis over the Check hybrid was estimated and tested for significance using standard methods (Rai and Rai, 2006).

RESULTS AND DISCUSSION

The mean sum of squares due to genotype was significant for all the traits in both the environments (Table 3), revealing genotypic variability for the traits studied. Pooled analysis (Table 3) showed that the mean squares due to environment were significant for all the traits except locule number and pericarp thickness, revealing the important role played by environment in the expression of most traits. G × E interaction was significant for three traits, viz., early yield, fruit weight and total yield, which meant that performance of the hybrids for these traits was significantly different under the two environments; whereas, environmental conditions did not influence expression of the other traits, viz., fruit number per vine, locule number, pericarp thickness and vine length. Overall mean early-yield, fruit number per vine, fruit weight and total fruit yield at Ludhiana (3.44 t ha^{-1}, 52.8, 62.6 g and 48.3 t ha^{-1} respectively) were significantly higher than those at Bathinda (2.46 t ha^{-1}, 37.9, 58.6 g and 36.5 t ha^{-1} respectively) (Table 4). This may be due to the higher organic carbon, available phosphorus, available potash and low electrical conductivity of the experimental soil at Ludhiana, compared to that in Bathinda (Table 2). Secondly, deficit irrigation during the month of April at Bathinda may also have been responsible for reduction in yield and yield contributing traits. According to Kalloo (1986), phosphorus application markedly increases early-yield, whereas, high nitrogen and potash improve the number of fruits and total fruit yield in tomato.

Earliness is one of the most important advantages of heterosis breeding in tomato facilitating the advantage of high prices during the early season, particularly, in regions with short growing-season such as in Punjab (Atanassova and Georgiev, 2007). All the experimental hybrids, except TH-11, gave significantly higher early-yield than TH-1 in both the environments (Table 4). Pooled analysis showed that maximum early-

Table 1. Monthly agro-meteorological record during the crop season at two locations in Punjab

Month and year	Air temperature (°C)			Relative humidity (%)		Rainfall (mm)	Evaporation (mm)	
E_1	Max.	Min.	Mean	Morning	Evening	Mean		
Nov. 2010	27.1	11.4	19.3	92	40	67	0.0	63.7
Dec. 2010	20.5	5.6	13.1	97	55	76	17.6	37.8
Jan. 2011	16.0	5.2	10.6	96	67	82	5.4	38.2
Feb. 2011	21.2	9.4	14.6	95	67	81	44.2	55.6
March 2011	27.9	13.4	20.6	92	54	73	6.5	117.9
April 2011	33.8	17.6	24.9	71	28	48	26.5	187.0
May 2011	39.4	25.0	32.2	57	32	45	34.4	277.1
E_2								
Nov. 2010	27.8	11.2	19.5	91	29	60	0.0	106.4
Dec. 2010	20.6	4.7	12.7	94	46	70	14.8	45.5
Jan. 2011	15.7	4.8	10.3	94	58	76	1.2	35.0
Feb. 2011	21.1	8.3	14.7	96	56	76	36.4	49.6
March 2011	28.2	12.4	20.3	91	44	68	0.0	115.2
April 2011	34.5	17.3	25.9	81	33	57	2.6	215.6
May 2011	41.0	24.4	32.7	58	24	41	28.0	297.2

E_1 = At Ludhiyna
E_2 = At Bathinda

Table 2. Characteristics of experimental soil (0-15 cm soil profile) at two locations in Punjab

Soil character	E_1	E_2
Soil texture	Sandy Loam	Loamy Sand
pH	7.6	8.2
Electrical conductivity (m mhos cm^{1})	0.21	0.31
Organic carbon (%)	0.33	0.17
Available phosphorus (kg ha^{-1})	28.4	12.2
Available potassium (kg ha^{1})	310.0	270.0

Table 3. Analysis of variance for seven traits in seven elite F_1 hybrids of tomato grown at two locations in Punjab

Source of variation	d.f.	Trait						
		Early yield ($t\ ha^{-1}$)	Fruit number per vine	Fruit weight (g)	Locule number	Pericarp thickness (mm)	Vine length (cm)	Total fruit yield ($t\ ha^{-1}$)
E_1		Mean sum of squares						
Replication	2	0.013	22.931	6.794	0.013	0.116	2.363	18.080*
Genotype	6	2.664*	157.171*	88.608*	0.224*	0.364*	3907.616*	146.188*
Error	12	0.081	7.932	4.911	0.015	0.052	6.269	4.495
E_2								
Replication	2	0.109	1.528	71.897*	0.008	0.012	262.650	2.104
Genotype	6	1.629*	109.169*	128.937*	0.196*	0.296*	3804.651*	142.602*
Error	12	0.061	3.872	4.997	0.017	0.060	116.248	2.882
Pooled								
Replication (within environment)	4	0.061	12.230	39.346*	0.010	0.064	132.507	10.092
Environment (E)	1	10.104*	2343.039*	165.22*	0.002	0.040	1273.813*	1479.758*
Genotype (G)	6	3.817*	259.119*	202.549*	0.405*	0.618*	7659.563*	273.323*
Interaction (G × E)	6	0.476*	7.221	14.997*	0.014	0.042	52.698	15.257*
Error	24	0.071	5.902	4.954	0.016	0.056	61.259	3.689

*Significant at 5% level

Table 4. Mean performance of seven elite F_1 hybrids of tomato evaluated at two locations in Punjab for seven traits

Sl. No.	F_1 hybrid	Early yield (t ha^{-1})			Fruit number per vine			Fruit weight (g)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1.	TH-11	2.23	1.55	1.89	52.3	37.2	44.7	60.6	56.5	58.5
2.	TH-13	3.51	2.64	3.07	60.7	43.5	52.1	61.8	55.2	58.5
3.	TH-16	3.63	2.67	3.15	57.2	41.1	49.2	57.8	51.9	54.8
4.	TH-21	4.02	3.44	3.73	46.7	33.2	39.9	73.2	72.2	72.7
5.	TH-22	4.73	2.51	3.62	50.5	33.2	41.8	64.9	56.4	60.6
6.	TH-23	3.82	3.01	3.42	60.8	46.6	53.7	62.7	60.9	61.8
7.	TH-1	2.15	1.42	1.78	41.6	30.4	36.0	57.0	57.0	57.0
General Mean		3.44	2.46	2.95	52.8	37.9	45.4	62.6	58.6	60.6
C.V. (%)		8.26	10.04	9.02	5.33	5.19	5.36	3.54	3.81	3.67
C.D. (G) (Pd”0.05)		0.51	0.44	0.32	5.0	3.5	2.9	3.9	4.0	2.6
C.D. (E) (Pd”0.05)				0.17			1.5			1.4
C.D. (G × E) (Pd”0.05)				0.45			NS			3.8

Table 4. contd…..

Sl.No.	F_1 hybrid	Locule number			Pericarp thickness (mm)			Vine length (cm)			Total fruit yield (t ha^{-1})		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1.	TH-11	2.37	2.33	2.35	7.10	7.33	7.22	166.7	149.1	157.8	46.4	37.8	42.1
2.	TH-13	2.10	2.20	2.15	7.00	6.87	6.93	175.0	166.7	170.8	54.9	42.1	48.5
3.	TH-16	2.00	2.00	2.00	6.80	7.03	6.92	169.9	167.1	168.5	48.4	36.0	42.2
4.	TH-21	2.70	2.60	2.65	7.10	7.00	7.05	164.8	158.3	161.6	50.1	36.9	43.5
5.	TH-22	2.10	2.00	2.05	6.70	6.80	6.75	178.1	159.0	168.5	48.0	30.4	39.2
6.	TH-23	2.00	2.13	2.07	6.90	6.80	6.85	168.8	155.5	162.2	55.9	46.4	51.2
7.	TH-1	2.50	2.60	2.55	6.10	6.30	6.20	75.9	66.5	71.2	34.7	25.7	30.2
General Mean		2.25	2.27	2.26	6.81	6.88	6.85	157.0	146.0	151.5	48.3	36.5	42.4
C.V. (%)		5.44	5.67	5.55	3.36	3.55	3.46	1.59	7.38	5.16	4.39	4.65	4.53
C D (G) (Pd”0.05)		0.22	0.23	0.15	0.41	0.43	0.28	4.4	19.2	9.3	3.8	3.0	2.3
C D (E) (Pd”0.05)				NS			NS			5.0			1.2
C D (G × E) (Pd”0.05)				NS			NS			NS			3.2

E_1 = At Ludhiyna
E_2 = At Bathinda

yield was produced in TH-21 (3.73 t ha^{-1}), which was statistically at par with TH-22 (3.62 t ha^{-1}) and TH-23 (3.42 t ha^{-1}). However, due to presence of G × E interaction for this trait, results with respect to the location differed significantly. Hybrid TH-22 gave maximum early-yield (4.73 t ha^{-1}) at Ludhiana, whereas at Bathinda, hybrid TH-21 produced the highest early-yield (3.44 t ha^{-1}) which was statistically at par with TH-23 (3.01 t ha^{-1}) (Table 4). Pooled standard heterosis over TH-1 ranged from 74.6% (TH-13) to 114.8% (TH-21).

Fruit number is an important yield-contributing trait in tomato. Maximum fruit number was recorded in TH-23, which was statistically at par with TH-13 at both the locations. The same trend was observed in total fruit yield, showing a close correlation between these two traits (Table 4). All the experimental hybrids gave significant, positive standard heterosis over TH-1 for these traits at both the locations, except TH-21 and TH-22 for fruit number at Bathinda (Table 5). Pooled standard heterosis ranged from 10.6% (TH-21) to 49.7% (TH-23) for fruit number and from 39.6% (TH-22) to 88.3% (TH-23) for total fruit-yield. Garg and Cheema (2014) also reported standard heterosis upto 102.28% and 165.88% over TH-1 for fruit number per plant and total fruit-yield, respectively. On the other hand, TH-21 recorded maximum fruit weight at both the locations (Table 4). Standard heterosis of 57.8% exhibited by TH-21 for total fruit-yield was contributed to mainly the 27.6% increase in fruit weight and 10.6% increase in fruit number (Table 5).

Locule number and pericarp thickness are important fruit-quality parameters which influencing fruit flavour, firmness, shelf-life and transportation to distant locales. Locule number in all the hybrids varied from 2.00 to 2.65 (Table 4). Maximum locule number (2.65) was seen in TH-21, which was statistically at par with TH-1 (2.55) and significantly higher than all the other hybrids. On the other hand, minimum locule number (2.00) was recorded by TH-16, which was at par with TH-22 (2.05), TH-23 (2.07) and TH-13 (2.15) (Table 4). All the hybrids, excepting TH-21, exhibited significant, negative standard heterosis over TH-1, ranging from -7.8% (TH-11) to -21.6% (TH-16) (Table 5). Garg and Cheema (2014) also observed standard heterosis over TH-1 as ranging from -39.94% to 50.15% for locule number.

Table 5. Heterosis over TH-1 (%) for seven traits exhibited by six elite F_1 hybrids of tomato evaluated at two locations of Punjab

F_1 Hybrid	Early yield			Fruit number per vine			Fruit weight		
	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
TH-11	3.9	8.9	6.4	25.8*	22.1*	23.9*	6.2	-0.9	2.7
TH-13	63.3*	85.9*	74.6*	45.9*	43.0*	44.4*	8.4*	-3.1	2.7
TH-16	69.0*	87.9*	78.4*	37.5*	34.9*	36.2*	1.3	-8.9*	-3.8
TH-21	87.1*	142.4*	114.8*	12.2*	9.1	10.6*	28.4*	26.7*	27.6*
TH-22	120.2*	76.5*	98.3*	21.4*	9.0	15.2*	13.9*	-1.0	6.5*
TH-23	77.7*	112.0*	94.8*	46.2*	53.2*	49.7*	10.1*	6.8	8.5*

E_1= At Ludhiyna
E_2= At Bathinda

Table 5. contd…….

F_1 Hybrid	Locule number			Pericarp thickness			Vine length			Total fruit yield		
	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	C_1	C_2	Pooled
TH-11	-5.3	-10.3*	-7.8*	16.4*	16.4	16.4*	119.6*	124.2*	121.9*	33.6*	75.1*	54.4*
TH-13	-16.0*	-15.4*	-15.7*	14.8*	9.0	11.9*	130.6*	150.7*	140.7*	58.1*	95.0*	76.5*
TH-16	-20.0*	-23.1*	-21.6*	11.5*	11.6	11.6*	123.9*	151.3*	137.6*	39.5*	66.9*	53.2*
TH-21	8.0	0.0	4.0	16.4*	11.1	13.8*	117.2*	138.0*	127.6*	44.3*	71.3*	57.8*
TH-22	-16.0*	-23.1*	-19.6*	9.8*	7.9	8.9*	134.6*	139.1*	136.9*	38.4*	40.8*	39.6*
TH-23	-20.0*	-17.9*	-18.9*	13.1*	7.9	10.5*	122.4*	133.8*	128.1*	61.2*	115.3*	88.3*

*Significant at 5% level

Pericarp thickness in all the hybrids varied from 6.20 mm to 7.22 mm. Maximum pericarp thickness (7.22 mm) was observed in TH-11, which was statistically at par with TH-21 (7.05 mm) and significantly higher than in all the other hybrids. On the other hand, minimum pericarp thickness (6.20 mm) was seen in TH-1, which was significantly lower than in all the other hybrids (Table 4). All the experimental hybrids showed significant, positive standard heterosis over TH-1, ranging from 8.9% (TH-22) to 16.4% (TH-11) (Table 5). Standard heterosis ranging from -21.88% to 71.51% was also reported by Garg and Cheema (2014) for pericarp thickness.

Vine length in tomato also contributes fruit yield (Atanassova and Georgiev, 2007). All the experimental hybrids had significantly higher vine length than TH-1 under both the environments (Table 4). Pooled analysis showed that maximum vine length was recorded in TH-13 (170.8 cm), which was at par with TH-16 (168.5 cm), TH-22 (168.5 cm), TH-23 (162.2 cm) and TH-21 (161.6 cm). The magnitude of standard heterosis over TH-1 varied from 121.9% (TH-11) to 140.7% (TH-13) (Table 5).

High yield is one of the most important advantages of heterosis breeding in tomato. Maximum pooled fruit-yield was exhibited by TH-23 (51.2 t ha^{-1}), followed by TH-13 (48.5 t ha^{-1}) and TH-21 (43.5 t ha^{-1}) (Table 4). All the experimental hybrids showed significant, positive heterosis over TH-1 ranging from 39.6% (TH-22) to 88.3% (TH-23) (Table 5). Standard heterosis for total fruit-yield in tomato ranges from 66.56 to 165.88%, as reported by Garg and Cheema (2014).

G × E interaction was significant for early-yield, fruit weight and total fruit-yield (Table 4). All the hybrids showed significant differences in early-yield and total fruit-yield, across the two locations. However, two hybrids, i.e., TH-21 and TH-1, exhibited at-par values for fruit weight across the two locations (Table 4). Therefore, on the basis of stability and superiority for fruit weight, fruit number, early and total yield, TH-21 is the most promising hybrid, followed by TH-23.

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