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GENETIC ANALYSIS FOR THE DETERMINATION OF HETEROSIS AND COMBINING ABILITY OF TOMATO FRUIT MORPHOLOGICAL TRAITS UNDER FROST STRESS

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Tomato production in Pakistan is facing stagnation due to different biotic and abiotic stresses. Tomato crop thrives well at temperatures ranging from 13 to 30°C. Tomato plants are sensitive to chilling temperature (0-12°C), therefore, its yield is affected by frost and low temperature. Hence, chilling stress is the major yield limiting factor for tomato cultivation in the plain areas of Pakistan. In order to develop high yielding frost/chilling tolerant tomato varieties/hybrids, there is need to exploit the existing variability for different yield related traits in tomato. The present study was designed to undertake the genetic analysis of various quantitative traits of economic worth. Among all the screened genotypes, only 18 lines were identified as frost tolerant. The selected lines were crossed with three high yielding testers. The parents and the F_1 hybrids were planted at two different locations (Faisalabad and Sialkot). The data for various fruit morphology traits were recorded and subjected to biometrical analysis to evaluate variability in parents and off springs. The yield performance of hybrids was evaluated at two different locations as a step towards the development of genetically improved indigenous hybrids/varieties in tomatoes. Maximum heterosis (78.11%) for marketable fruit yield per plant was calculated in F_1 hybrid resulting from a cross involving 017856 and Roma. Likewise, maximum heterosis for fruit length, width and weight was recorded for F_1 hybrids of BSX-717-1-1 × Roma (20.67%), Rutgar Sala × Nagina (50.80%) and CLN-2418 A × Roma (44.90%), respectively. Hence, suggesting the use of these parental genotypes for the development of frost tolerant and high yielding tomato varieties.

Keywords: Biplot analysis, heterosis, line × tester, frost stress, yield components

INTRODUCTION

Vegetables are packed with antioxidants, vitamins and important minerals, which are essential for human health. The recommended daily per capita consumption of vegetables is 400 g (FAO/WHO Report, 2003). The vegetable intake in Pakistan is very low, which is approximately 100 g per capita (Pollack, 2001). Among all the vegetables; cultivated tomato is relatively a recent addition to the world's important food crops. Its prime significance is due to its qualities for human nutrition and its economic value. In order to extend its viable life, it is harvested either unripen or in mature fruit state and stored at low temperatures (Re *et al*., 2012). Storage of tomato as an originally tropical fruit is limited by the risk of chilling injury (CI) (Bourne, 2006). However, chilling and cold stress have become major limiting factors for its yield, growth, reproduction, biochemical, physiological, morphological and agronomic properties. An important aim of crop improvement includes production of high-yielding varieties with abiotic stress resistance. Cold has a huge blow on agriculture since there are a small number of areas free from abiotic stresses in which crops can attain their utmost potential. These unfavorable environmental stresses can cause the death of plants and restricts the agricultural yield (Jan *et al*., 2009). The chilling temperature between 0 and 12°C produces a serious harm to tropical and subtropical plants including tomato (Zhang *et al*., 2009). Tomato is very sensitive to low temperature (Shah *et al*., 2015). Plant acts in response to cold stress to stay alive and various sorts of changes occur in the cellular, molecular and physiological levels of their growth and fruit development (Porta *et al*., 2014). Hazra *et al*. (2007) summarized symptoms associated with fruit set failure at chilling temperature in tomato, including bud drop, abnormal flower development, poor pollen production, dehiscence and viability, ovule abortion and poor viability, reduced carbohydrate availability and other reproductive abnormalities. It is reported that the exposure of chilling-sensitive plants to low temperatures causes disturbances in all physiological processes; water regime, mineral nutrition, photosynthesis, respiration and metabolism. Inactivation of metabolism observed at chilling of chilling-sensitive plants is a complex function of both temperature and duration of exposure (Moustafa *et al*., 2006). By understanding the valid genetic basis and evaluation of inbreds and hybrid performance under chilling stress one can design an appropriate breeding strategies for variety/hybrid development in tomatoes. The available tomato germplasm was screened for tolerance to chilling temperatures. The heterosis and better parent heterosis was estimated in the crosses involving selected lines, as a step towards the development of genetically improved indigenous hybrids/varieties in tomatoes. The present studies were focused on the screening of a wide array of tomato genotypes against the frost stress. The diversity of the tomato accessions will be useful to exploit heterosis for the economically important traits. The main objectives of the study were to evaluate lines, testers and their crosses for different yield and fruit morphology related traits under chilling stress environments, and select tomato hybrid(s) with improved yield and overall performance.

MATERIALS AND METHODS

***Germplasm collection and screening*:** A total of 75 genotypes were collected from the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad and Vegetable Research Institute, Ayub Agricultural Research Institute, Faisalabad. The plant material was planted in the open field, research area of the Vegetable Research Institute, Ayub Agricultural Research Institute, Faisalabad in 2007 in order to screen against the frost tolerance. Out of these, 18 lines were survived. The seed from the survived material was collected. The survived material hence screened showed tolerance which is due to the presence of the frost tolerant genes.

***Germplasm crossing*:** Out of these, eighteen tomato genotypes (chilling tolerant), eighteen genotypes were treated as female and were crossed with three genotypes as male to develop 54 crosses in line × tester mating design (Table 1). The crossing attempts were made in the research area. The three male parents viz; Nagina, Roma and Pakit. The choice of the male parents was on the basis of their best performance and popularity among the farming community. The salient traits of the testers are given in Table 2. In order to facilitate crossing work, only 15-20 flowers/plant were crossed by following standard procedure (Kimura and Sinha, 2008).

***Morphological traits measurement*:** The F_1 and selected parents seed was planted in a nursery during the last week of October, 2008. The nursery was grown on raised beds. Application of N:P:K @ 90:45:75 kg per acre were used. 1/3rd of N while full doses of P and K were applied at the time of transplanting while the rest of the N was applied at flowering and fruit development stages. The seedlings of selected parents and F_1 hybrids were transplanted in the field at two different locations (Sialkot and Faisalabad) in three replications during the first week of December, 2008 in Randomized Complete Block Design. Net plot size was kept as 5.0 × 1.25 m, with plant spacing of 50 cm and transplanting on one side of the raised beds. Necessary agronomic and plant protection practices were applied. Since there were insufficient frosty nights during 2008-09, therefore, the data for different morphological traits was also recorded during 2011-12.

Table 1. Frost tolerant parental lines and crosses of tomato.

Sr.	Genotype	Sr.	Genotype
1	TY-18 A	39	Eden Oblong × Nagina
2	BSX-717-1-1	40	TY-18 A × Roma
3	UK	41	BSX-717-1-1 × Roma
4	CLN-5915-93-D-4-1-1-3	42	UK × Roma
5	CLN-1744-23	43	CLN-5915-93-D-4-1-1-3×Roma
6	017856	44	CLN-1744-23 × Roma
7	BSX-935-3-1-2	45	017856 × Roma
8	Samara Clauz Bonanza	46	BSX-935-3-1-2 × Roma
9	017904	47	Samara Clauz Bonanza×Roma
10	017890	48	017904 × Roma
11	STD-552 F_2	49	017890 × Roma
12	88572	50	STD-552 F_2 × Roma
13	Rutgar Sala	51	88572 × Roma
14	017887	52	Rutgar Sala × Roma
15	CLN-2160	53	017887 × Roma
16	CLN-2418 A	54	CLN-2160 × Roma
17	Xi Yu-903	55	CLN-2418 A × Roma
18	Eden Oblong	56	Xi Yu-903 × Roma
19	Nagina	57	Eden Oblong × Roma
20	Roma	58	TY-18 A × Pakit
21	Pakit	59	BSX-717-1-1 × Pakit
22	TY-18 A × Nagina	60	UK × Pakit
23	BSX-717-1-1 × Nagina	61	CLN-5915-93-D-4-1-1-3×Pakit
24	UK × Nagina	62	CLN-1744-23 × Pakit
25	CLN-5915-93-D-4-1-1-3×Nagina	63	017856 × Pakit
26	CLN-1744-23 × Nagina	64	BSX-935-3-1-2 × Pakit
27	017856 × Nagina	65	Samara Clauz Bonanza × Pakit
28	BSX-935-3-1-2 × Nagina	66	017904 × Pakit
29	Samara Clauz Bonanza×Nagina	67	017890 × Pakit
30	017904 × Nagina	68	STD-552 F_2 × Pakit
31	017890 × Nagina	69	88572 × Pakit
32	STD-552 F_2 × Nagina	70	Rutgar Sala × Pakit
33	88572 × Nagina	71	017887 × Pakit
34	Rutgar Sala × Nagina	72	CLN-2160 × Pakit
35	017887 × Nagina	73	CLN-2418 A × Pakit
36	CLN-2160 × Nagina	74	Xi Yu-903 × Pakit
37	CLN-2418 A × Nagina	75	Eden Oblong × Pakit
38	Xi Yu-903 × Nagina		

Table 2. Salient characteristics of the three testers.

Variety/line	Traits
Nagina	Earliness in maturity, thick pericarp, less juice contents, pear shaped fruit, high yielding, good shelf life and approved variety.
Pakit	Early line, medium pericarp thickness, more juice contents, oval shaped fruit, fair yield and unapproved line.
Roma	Early in maturity, thin pericarp, more juice contents, plum shaped fruit, fair yield, less shelf

life and suitable for canning.

At maturity, 10 consecutive plants per genotype (excluding bordered plants) were marked and data was recorded for fruit length (mm), fruit width (mm), fruit weight (g), pericarp thickness (mm), fruit setting percentage per plant (Weaver and Timm, 1989, Abdul-Baki, 1991), fruit firmness at pink class stage (Kg/cm^2) measured with Penetrometer by puncture method (Kader *et al*., 1978a, b) and marketable fruit yield per plant (kg).

***Biometrical approaches*:** The data collected for various parameters were statistically analyzed using analysis of variance (Steel *et al*., 1997). Pooled analysis of variance (ANOVA) for two environments and separate ANOVA for each environment were performed to determine if different chilling temperature significantly affected various parameters. Duncan's Multiple Range Test (DMR) was used for mean separation among significantly different genotypes. Percent heterosis over mid parent and better parent was computed after calculating heterosis on respective parent using formulae proposed by Falconer and Mackay (1996). Biplot analysis was used to compare the performances of parental lines and F_1 hybrids under chilling stress and without stress (Yan, 2001).

RESULTS

***Genetic variability for different yield related traits under growing conditions of Faisalabad*:** The results pertaining to the analysis of variance for different quality and yield related traits are given in Table 3. The results have shown highly significant ($p \geq 0.01$) differences among tomato genotypes for all the traits studied. The sum of squares of tomato genotypes for these traits were partitioned into parents, crosses and parents vs crosses, revealing highly significant differences for all the traits except pericarp thickness, and marketable fruit yield per plant in parent vs crosses. No significant differences were also observed for pericarp thickness and marketable fruit yield per plant in testers. Highly significant differences existed among lines for all the traits. However, highly significant ($p \geq 0.01$) differences were displayed by line × tester interaction for all the studied traits (Table 4).

***Genetic Variability for different yield related traits under growing conditions of Sialkot*:** The results of analysis of variance for all the yield contributing traits studied in this study has revealed highly significant ($p \geq 0.01$) differences among tomato genotypes (Table 3). The sum of squares of tomato genotypes for all the traits were partitioned into parents, crosses and parents vs crosses revealing highly significant differences for all the traits except pericarp thickness and fruit width in parent vs crosses. Similarly, all the testers have shown significant similarities for marketable fruit yield per plant. Highly significant differences existed among lines for all yield contributing traits. Highly significant ($p \geq 0.01$) differences were also displayed by line × tester interaction for all the traits under study (Table 5).

Table 3. Analysis of variance for the genotypes grown at Faisalabad and Sialkot.

SOV	Faisalabad		Sialkot	
	Replication	Treatments	Replications	Treatments
DF	2	74	2	74
Traits				
FF	2.29 $^{N.S}$	2.70**	3.05 $^{N.S}$	5.67**
FS % /P	6.18**	19.38**	0.18 $^{N.S}$	15.54**
MFY/P	3.01 $^{N.S}$	31.24**	0.78 $^{N.S}$	52.45**
PT	0.11 $^{N.S}$	5.16**	0.20 $^{N.S}$	63.91**
FL	6.49**	155.38**	1.00 $^{N.S}$	78.09**
FW	1.07 $^{N.S}$	201.43**	1.59 $^{N.S}$	912.68**
FWi	6.61**	45.54**	0.12 $^{N.S}$	100.08**

*=Significant at 0.05 probability level **= Highly significant at 0.01 probability level **N.S**=Non Significant

SOV = Source of Variation, DF = Degrees of freedom, FF = Fruit firmness at pink class stage (Kg/cm^2), FS % /P = Fruit setting

Table 4. Mean squares from the analysis of variance for different yield related traits under growing conditions of Faisalabad.

SOV	Replications	Treatments	Parents	Parents vs Crosses	Crosses	Lines	Testers	Line × testers	Error
DF	2	74	20	1	53	17	2	34	148
Traits									
FF	1.39$^{N.S}$	1.65**	1.14*	3.30*	1.81**	2.48**	8.84**	1.06*	0.61
FS % /P	27.15**	85.08**	64.47**	81.75**	92.92**	139.75**	100.28**	69.07**	4.38
MFY/P	0.08$^{N.S}$	0.87**	0.82*	0.005$^{N.S}$	0.91**	1.30**	0.04$^{N.S}$	0.77**	0.028
PT	0.04$^{N.S}$	1.99**	2.90**	0.09$^{N.S}$	1.68**	2.61**	1.00$^{N.S}$	1.25**	0.38
FL	8.20**	196.2**	261.00**	35.30**	174.86**	368.70**	272.26**	72.21**	1.26
FW	1.76$^{N.S}$	331.1**	542.9**	47.3**	256.5**	375.4**	252.9**	197.3**	1.64
FWi	9.87**	68.09**	103.80**	19.79**	55.53**	82.39**	62.25**	41.71**	1.49

*=Significant at 0.05 probability level **= Highly significant at 0.01 probability level, **N.S**=Non Significant

SOV = Source of Variation, DF = Degrees of freedom, FF = Fruit firmness at pink class stage (Kg/cm^2), FS % /P = Fruit setting percentage per plant, MFY/P = Marketable fruit yield per plant (kg), PT = Pericarp thickness (mm), FL = Fruit length (mm), FW = Fruit weight (g), FWi = Fruit width (mm).

Table 5. Mean squares from the analysis of variance for different yield related traits under growing conditions of Sialkot.

SOV	Replications	Treatments	Parents	Parents Vs Crosses	Crosses	Lines	Testers	Line × testers	Error
DF	2	74	20	1	53	17	2	34	148
Traits									
FF	0.80 N.S	1.49**	0.95**	2.95**	1.67**	2.42**	8.11**	0.91**	0.26
FS % /P	2.15 N.S	183.87**	156.82**	254.00**	192.76**	267.36**	24.78 N.S	165.33**	11.83
MFY/P	0.013 N.S	0.877**	0.703**	0.206**	0.955**	1.348**	0.001 N.S	0.814**	0.017
PT	0.006 N.S	1.832**	2.511**	0.022 N.S	1.609**	2.519**	1.208**	1.178**	0.029
FL	2.24 N.S	175.21**	256.60**	48.05**	146.89**	293.29**	213.81**	69.75**	2.24
FW	0.57 N.S	325.18**	517.95**	28.76**	258.03**	379.25**	236.46**	198.69**	0.36
FWi	0.08 N.S	66.84**	93.08**	2.19 N.S	58.16**	89.69**	65.27**	41.97**	0.67

* = Significant at 0.05 probability level ** = Highly significant at 0.01 probability level **N.S** = Non Significant
SOV = Source of Variation, DF = Degrees of freedom, FF = Fruit firmness at pink class stage (Kg/cm2), FS % /P = Fruit setting percentage per plant, MFY/P = Marketable fruit yield per plant (kg), PT = Pericarp thickness (mm), FL = Fruit length (mm), FW = Fruit weight (g), FWi = Fruit width (mm).

percentage per plant, MFY/P = Marketable fruit yield per plant (kg), PT = Pericarp thickness (mm), FL = Fruit length (mm), FW = Fruit weight (g), FWi = Fruit width (mm).

Heterosis estimates for tomato fruit morphology traits under the growing conditions of Faisalabad and Sialkot:

Fruit length: Heterosis for fruit length over mid and better parental values among all the crosses is given in Table 6. The data has revealed that cross BSX-717-1-1 × Roma had maximum value of positive better parent heterosis for this trait followed by the cross combination involving CLN-2418 A and Pakit.

Pericarp thickness: The variable magnitude and direction of Better parent heterosis for pericarp thickness was observed. It was recorded that the cross combination STD-552 × Roma had maximum positive value of Better parent heterosis for this trait followed by CLN-2418 A × Nagina and 88572 × Nagina respectively (Table 6).

Fruit width: For majority of the crosses, negative values of better parent heterosis for fruit width were observed. Maximum values of positive better parent heterosis for this trait were observed in Rutgar Sala × Nagina followed by Rutgar Sala × Roma and 017887 × Nagina respectively (Table 7).

Fruit weight: The heterosis manifestation in hybrids for fruit weight is presented in Table 7, revealing significant variation in magnitude and direction. For most of the hybrids the heterosis estimates were negative. Maximum values of positive better parent heterosis for this trait were observed in CLN-2418 A × Roma followed by STD-552 × Pakit and UK × Pakit, respectively.

Fruit setting percentage per plant: The results pertaining to heterotic manifestation of all the crosses for fruit setting percentage per plant has revealed variation in magnitude and direction with cross combination CLN-1744-23 × Nagina having the maximum and positive better parent heterosis for this trait. Cross combinations 017887 × Pakit and CLN-1744-23 × Pakit had maximum positive of better parent heterosis for Fruit setting percentage per plant under the growing conditions of Sialkot (Table 8).

Marketable fruit yield per plant: The heterosis manifestation of all the crosses for marketable fruit yield per plant is presented in Table 8. Hybrid combination Xi Yu-903 × Roma had maximum positive better parent heterosis for this trait followed by Rutgar Sala × Pakit and STD-552 × Roma, respectively (Table 8).

Fruit firmness at pink class stage: Heterosis affects fruit firmness at pink class stage and has revealed significant variation in magnitude and direction. The highest positive value of better parent heterosis for this trait was shown by the cross combination 017887 × Pakit followed by CLN-2160 × Pakit and Samara Clauz Bonanza × Pakit, respectively (Table 9).

Biplot analysis for different fruit and yield related traits of tomato under the growing conditions of Faisalabad and Sialkot during the year 2008 and 2012:

Biplot analysis for different yield and fruit related traits was carried out for 21 parental lines including three males, eighteen female parental genotypes and 54 crosses (list of parents and hybrids along with codes is given in Table 1). This analysis was performed to check the performance of parents and F_1 hybrids in two different environments of Faisalabad and Sialkot during year 2008 and 2012, respectively.

Fruit length and pericarp thickness: Fruit length is basic trait for fruit size in tomato. Under Faisalabad conditions; the genotype 18 showed the maximum fruit length and pericarp thickness followed by genotype 41 which was hybrid of BSX-717-1-1 × Roma. While Hybrid 40 followed by genotype 6 showed minimum fruit length and pericarp thickness. The results of biplot analysis suggested that fruit length and pericarp thickness has highest positive correlation and vectors of both traits were overlapping to each other

(Fig. 1). In case of Sialkot, FL and PT were less correlated and their vectors were on the same side. Genotypes 17 and 18 followed hybrid 55 demonstrated highest FL and PT respectively. While Hybrid 40 and 70 followed by genotype 6 showed minimum

Table 6. Heterotic manifestation in hybrids for fruit length and pericarp thickness.

Crosses	Fruit length				Pericarp thickness			
	Heterosis		Better parent heterosis		Heterosis		Better parent heterosis	
	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot
TY-18 A × Nagina	-20.64	-24.50	-35.00	-37.74	-22.67[a]	-22.37[b]	6.13	6.20
BSX-717-1-1 × Nagina	-21.89	-24.80	-29.00	-31.02	3.95	3.41	6.13	6.20
UK × Nagina	-7.87	-5.34	-20.00	-17.58	3.57	-2.33	6.13	6.20
CLN-5915-93-D-4-1-1-3 × Nagina	-19.19	-22.00	-33.70	-35.90	-4.40	-4.88	6.13	6.20
CLN-1744-23 × Nagina	-19.11	-18.90	-31.90	-32.68	-6.17	-1.89	6.13	6.20
017856 × Nagina	-27.99	-27.50	-43.10	-42.22	-4.52	-3.49	6.13	6.20
BSX-935-3-1-2 × Nagina	-18.34	-20.10	-18.90	-22.46	-12.87	-9.18	7.33	6.87
Samara Clauz Bonanza × Nagina	-16.71	-21.60	-22.50	-26.82	-12.69	-13.57	7.00	7.07
017904 × Nagina	-17.46	-11.70	-30.50	-27.11	-10.27	-10.16	6.20	6.27
017890 × Nagina	-5.92	-11.50	-13.70	-18.95	0.00	3.33	6.13	6.20
STD-552 × Nagina	-14.23	-13.30	-23.60	-23.95	-4.09	-4.49	6.13	6.20
88572 × Nagina	-4.24	-11.50	-13.70	-19.64	3.78	3.74	6.20	6.27
Rutgar Sala × Nagina	6.27	4.53	-16.90	-19.13	0.00	1.20	6.13	6.20
017887 × Nagina	-0.48	-1.67	-15.80	-18.72	11.90	7.60	6.13	6.20
CLN-2160 × Nagina	-16.99	-18.50	-24.40	-26.19	-6.90	-4.05	6.13	6.20
CLN-2418 A × Nagina	13.10	9.61	1.58	-3.33	12.85	9.29	6.13	6.20
Xi Yu-903 × Nagina	-14.51	-13.20	-22.80	-21.83	8.88	5.26	6.13	6.20
Eden Oblong × Nagina	-10.39	-10.60	-11.60	-12.18	1.57	2.65	6.60	6.40
TY-18 A × Roma	-28.33	-31.40	-41.60	-42.94	-38.46	-38.36	6.53	6.67
BSX-717-1-1 × Roma	20.67	16.70	10.30	5.98	9.29	7.65	6.53	6.67
UK × Roma	-9.28	-8.47	-21.70	-19.63	-1.15	-7.82	6.53	6.67
CLN-5915-93-D-4-1-1-3 × Roma	-16.99	-12.20	-32.30	-27.30	1.21	-4.09	6.53	6.67
CLN-1744-23 × Roma	-13.87	-12.90	-27.90	-27.12	-2.38	3.01	6.53	6.67
017856 × Roma	-15.51	-14.30	-33.60	-31.17	10.56	6.99	6.53	6.67
BSX-935-3-1-2 × Roma	-6.31	-2.78	-7.55	-4.80	-4.81	-0.99	7.33	6.87
Samara Clauz Bonanza × Roma	-1.09	-2.80	-8.47	-8.44	-23.15	-25.24	7.00	7.07
017904 × Roma	-18.29	-18.50	-31.50	-32.16	-11.52	-11.86	6.53	6.67
017890 × Roma	-5.43	-7.04	-13.70	-14.12	4.84	4.81	6.53	6.67
STD-552 × Roma	-4.88	-6.86	-15.80	-17.63	25.42	19.46	6.53	6.67
88572 × Roma	-8.65	-3.61	-18.10	-11.66	-10.99	-13.40	6.53	6.67
Rutgar Sala × Roma	3.18	6.99	-19.70	-16.64	10.12	5.78	6.53	6.67
017887 × Roma	0.68	0.77	-15.20	-16.05	4.02	1.12	6.53	6.67
CLN-2160 × Roma	-12.54	-11.10	-20.80	-18.80	-10.00	-11.67	6.53	6.67
CLN-2418 A × Roma	7.58	7.15	-3.92	-4.69	3.24	3.16	6.53	6.67
Xi Yu-903 × Roma	-35.07	-34.10	-41.70	-40.13	-20.57	-20.22	6.53	6.67
Eden Oblong × Roma	2.15	-2.01	0.12	-2.75	1.02	2.04	6.60	6.67
TY-18 A × Pakit	-3.08	0.40	-13.10	-8.08	-3.61	-4.24	7.20	7.07
BSX-717-1-1 × Pakit	-5.50	-5.19	-21.70	-21.69	-14.51	-14.29	7.20	7.07
UK × Pakit	1.10	3.35	-3.19	0.66	-2.72	-1.62	7.20	7.07
CLN-5915-93-D-4-1-1-3 × Pakit	-12.21	-9.43	-21.20	-17.47	-10.86	-10.73	7.20	7.07
CLN-1744-23 × Pakit	-9.65	-8.88	-16.50	-16.01	-17.98	-12.79	7.20	7.07
017856 × Pakit	-3.71	-0.50	-17.20	-12.48	-8.77	-11.44	7.20	7.07
BSX-935-3-1-2 × Pakit	-11.84	-10.60	-20.00	-18.09	-10.09	-5.26	7.33	7.07
Samara Clauz Bonanza × Pakit	-7.99	-5.96	-11.00	-10.54	-9.39	-10.85	7.20	7.07
017904 × Pakit	-8.43	-4.97	-15.20	-12.92	-23.38	-25.50	7.20	7.07
017890 × Pakit	-7.30	-7.44	-9.01	-10.16	-10.71	-7.77	7.20	7.07
STD-552 × Pakit	-4.38	-0.22	-5.81	-2.06	-24.06	-23.56	7.20	7.07
88572 × Pakit	-1.74	-4.67	-1.81	-6.68	-8.96	-6.00	7.20	7.07
Rutgar Sala × Pakit	-18.64	-12.40	-30.80	-25.55	-21.91	-23.46	7.20	7.07
017887 × Pakit	-6.98	-9.40	-13.40	-16.89	-17.93	-19.02	7.20	7.07
CLN-2160 × Pakit	2.62	1.55	1.56	-0.21	1.05	-0.54	7.20	7.07

CLN-2418 A × Pakit	7.44	7.43	6.89	6.17	-22.05	-23.47	7.20	7.07
Xi Yu-903 × Pakit	-1.52	-0.15	-1.66	-1.36	-9.19	-5.98	7.20	7.07
Eden Oblong × Pakit	0.79	-1.81	-7.92	-11.12	-8.21	-10.40	7.20	7.07

Table 7. Heterotic manifestation in hybrids for fruit width and fruit weight.

Crosses	Fruit width				Fruit weight			
	Heterosis		Better parent heterosis		Heterosis		Better parent heterosis	
	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot
TY-18 A × Nagina	-7.22	-9.74	-7.81	-10.59	-17.63	-21.30	-31.20	-34.74
BSX-717-1-1 × Nagina	-0.78	-1.16	-7.69	-10.21	-4.14	-7.34	-13.40	-16.12
UK × Nagina	9.35	9.27	7.93	7.48	-8.01	-4.87	-12.80	-6.37
CLN-5915-93-D-4-1-1-3 × Nagina	-10.04	-12.70	-15.80	-17.34	-15.29	-16.90	-31.70	-33.63
CLN-1744-23 × Nagina	0.54	-2.15	-8.37	-9.53	-1.05	-0.85	-26.80	-27.47
017856 × Nagina	-5.44	-9.33	-11.40	-12.84	-23.31	-27.50	-46.00	-48.10
BSX-935-3-1-2 × Nagina	-6.96	-5.72	-7.52	-6.53	-14.40	-16.30	-24.90	-27.82
Samara Clauz Bonanza × Nagina	-8.92	-8.72	-9.82	-12.01	-17.63	-20.70	-27.40	-30.66
017904 × Nagina	-4.64	-0.12	-10.10	-7.88	20.07	20.24	-8.97	-10.38
017890 × Nagina	-2.27	-3.73	-9.82	-12.84	-12.68	-14.40	-29.20	-31.35
STD-552 × Nagina	-5.54	-3.97	-11.40	-8.33	-16.13	-14.90	-24.30	-21.89
88572 × Nagina	2.45	-0.52	-0.14	-1.47	-6.66	-9.68	-11.90	-16.06
Rutgar Sala × Nagina	50.00	50.80	37.20	35.44	34.01	34.07	6.85	5.40
017887 × Nagina	13.30	13.30	12.79	10.66	11.64	9.69	-11.00	-14.19
CLN-2160 × Nagina	-1.44	-1.54	-6.32	-9.01	-32.71	-35.10	-43.80	-46.16
CLN-2418 A × Nagina	-14.32	-14.80	-20.20	-18.33	-0.04	-2.67	-13.00	-16.61
Xi Yu-903 × Nagina	-18.75	-17.20	-29.70	-27.22	-7.59	-6.25	-25.40	-23.25
Eden Oblong × Nagina	6.44	7.24	2.51	3.45	-0.62	-1.19	-3.32	-4.98
TY-18 A × Roma	2.29	1.59	-6.01	-7.19	-14.94	-15.40	-24.90	-24.78
BSX-717-1-1 × Roma	-8.82	-9.17	-9.46	-9.47	3.11	-2.17	-0.97	-4.25
UK × Roma	16.88	18.63	6.75	5.88	-11.41	-6.37	-21.00	-14.81
CLN-5915-93-D-4-1-1-3 × Roma	3.36	5.86	2.01	1.01	-33.65	-31.90	-43.60	-41.95
CLN-1744-23 × Roma	13.11	11.93	11.39	9.46	-4.80	-5.18	-26.40	-26.66
017856 × Roma	5.35	3.90	3.83	-2.36	-15.78	-15.40	-38.20	-36.14
BSX-935-3-1-2 × Roma	0.94	3.43	-7.22	-5.58	-9.00	-5.33	-15.20	-12.10
Samara Clauz Bonanza × Roma	-8.20	-4.96	-14.40	-10.92	-33.71	-34.50	-38.00	-38.27
017904 × Roma	0.09	2.45	-1.98	0.44	-18.92	-18.60	-35.60	-35.73
017890 × Roma	6.38	9.21	6.19	9.16	-3.26	-3.15	-17.30	-17.01
STD-552 × Roma	11.66	14.30	-2.67	-0.68	-15.08	-16.50	-27.60	-28.77
88572 × Roma	-2.52	1.93	-12.00	-8.47	-20.35	-17.20	-20.90	-17.81
Rutgar Sala × Roma	22.36	27.45	20.99	26.27	20.65	23.71	1.29	3.68
017887 × Roma	3.68	4.13	-3.76	-3.62	8.11	9.47	-9.19	-8.75
CLN-2160 × Roma	1.96	6.02	-1.01	3.72	-7.40	-4.14	-18.20	-14.80
CLN-2418 A × Roma	-5.04	-1.42	-17.70	-13.99	44.87	43.90	33.70	32.62
Xi Yu-903 × Roma	-19.38	-15.60	-34.70	-31.83	-52.94	-49.90	-63.80	-61.45
Eden Oblong × Roma	2.74	-0.82	-1.56	-7.11	-1.20	-2.07	-4.85	-6.15
TY-18 A × Pakit	-3.41	-2.18	-4.55	-3.91	3.30	3.66	-14.40	-14.20
BSX-717-1-1 × Pakit	-1.44	0.29	-9.83	-9.59	-6.19	-6.41	-16.00	-15.44
UK × Pakit	3.76	2.20	3.23	1.38	9.66	11.86	4.80	10.32
CLN-5915-93-D-4-1-1-3 × Pakit	-6.70	-6.01	-14.20	-11.73	-30.53	-29.90	-44.40	-44.11
CLN-1744-23 × Pakit	-2.05	-4.10	-12.20	-12.03	-26.89	-23.30	-46.30	-43.97
017856 × Pakit	3.78	2.24	-4.40	-2.51	5.10	3.71	-26.40	-25.84
BSX-935-3-1-2 × Pakit	-3.30	-2.33	-4.48	-3.99	-28.82	-29.30	-38.00	-39.15
Samara Clauz Bonanza × Pakit	-6.00	-2.66	-8.58	-6.94	9.52	11.29	-4.23	-2.83
017904 × Pakit	-3.40	-1.69	-10.50	-10.04	-17.35	-21.20	-37.70	-41.35
017890 × Pakit	-2.67	-0.21	-11.70	-10.33	-21.41	-20.60	-36.80	-36.39
STD-552 × Pakit	3.39	5.53	-1.33	1.57	21.81	22.94	10.86	13.00
88572 × Pakit	-3.75	-3.21	-4.48	-3.31	-23.28	-22.30	-28.20	-27.91
Rutgar Sala × Pakit	-11.94	-7.78	-20.80	-17.79	-39.93	-38.20	-52.40	-51.48
017887 × Pakit	-10.62	-10.00	-12.60	-12.84	-16.85	-16.50	-34.10	-34.73
CLN-2160 × Pakit	-7.18	-6.32	-13.30	-14.1	-12.88	-16.60	-27.70	-30.94

CLN-2418 A × Pakit	-21.66	-19.10	-25.80	-21.78	-36.65	-37.20	-45.30	-46.31
Xi Yu-903 × Pakit	-9.71	-8.33	-20.70	-18.79	-24.8	-23.10	-38.80	-36.92
Eden Oblong × Pakit	5.97	5.44	0.29	0.89	-6.72	-7.50	-10.10	-11.23

Table 8. Heterotic manifestation in hybrids for fruit setting percentage per plant and Marketable fruit yield per plant.

Crosses	Fruit setting percentage per plant				Marketable fruit yield per plant			
	Heterosis		Better parent heterosis		Heterosis		Better parent heterosis	
	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot	Faisalabad	Sialkot
TY-18 A × Nagina	-2.24[a]	-7.70[b]	-3.97	-9.29	-11.81[a]	-14.58[b]	-18.64	-26.10
BSX-717-1-1 × Nagina	0.02	3.99	-1.91	2.79	15.16	10.90	6.67	10.45
UK × Nagina	-4.10	-3.15	-6.04	-4.24	13.84	17.56	2.11	11.63
CLN-5915-93-D-4-1-1-3 × Nagina	5.50	12.85	4.36	8.93	12.02	5.85	-1.27	-3.81
CLN-1744-23 × Nagina	13.28	15.88	12.36	15.66	38.82	32.90	31.31	32.08
017856 × Nagina	4.73	-0.12	3.67	-0.91	47.11	29.03	22.63	11.34
BSX-935-3-1-2 × Nagina	8.25	11.75	1.47	-2.11	7.58	11.27	-3.16	-0.67
Samara Clauz Bonanza × Nagina	-9.98	-9.70	-11.74	-14.78	-15.07	-12.00	-38.60	-34.64
017904 × Nagina	1.91	-0.05	0.08	-6.03	38.93	39.62	32.11	29.87
017890 × Nagina	6.10	0.62	3.84	0.01	-7.73	-1.51	-16.64	-6.82
STD-552 × Nagina	-3.90	-6.02	-7.38	-11.18	-12.26	-9.29	-21.12	-16.70
88572 × Nagina	-5.61	-4.28	-6.65	-4.57	-28.63	-25.64	-34.36	-30.36
Rutgar Sala × Nagina	-18.34	-21.01	-18.48	-22.56	-44.13	-34.08	-56.07	-50.68
017887 × Nagina	-7.32	-12.74	-8.89	-12.77	-37.06	-38.78	-42.40	-40.95
CLN-2160 × Nagina	7.59	15.01	4.62	6.92	-32.77	-30.49	-37.10	-32.31
CLN-2418 A × Nagina	-1.57	8.62	-6.82	0.20	17.31	4.53	3.16	-6.00
Xi Yu-903 × Nagina	-1.21	9.53	-10.45	-4.75	-3.24	4.18	-11.68	-4.16
Eden Oblong × Nagina	-1.05	-4.43	-1.50	-5.24	-22.83	-6.00	-31.30	-11.48
TY-18 A × Roma	3.03	4.52	-0.17	-0.06	-38.64	-31.70	-39.46	-33.95
BSX-717-1-1 × Roma	-10.33	-16.52	-10.83	-17.89	-33.01	-24.16	-41.70	-32.68
UK × Roma	-6.43	-3.85	-9.57	-7.53	-8.37	-6.77	-22.59	-20.62
CLN-5915-93-D-4-1-1-3 × Roma	4.00	13.19	1.47	6.36	13.59	23.23	-5.58	0.99
CLN-1744-23 × Roma	1.01	-1.20	0.42	-3.75	0.33	20.11	-10.98	6.42
017856 × Roma	6.17	7.22	3.65	3.46	78.11	72.30	57.47	66.12
BSX-935-3-1-2 × Roma	7.21	15.82	-0.80	-0.95	54.54	55.10	48.47	54.75
Samara Clauz Bonanza × Roma	0.54	-6.64	-2.77	-14.18	-29.87	-18.75	-46.93	-34.14
017904 × Roma	0.84	-2.95	0.42	-6.26	27.44	40.85	25.09	34.43
017890 × Roma	-4.94	4.75	-5.66	1.26	-7.18	2.87	-21.07	-12.69
STD-552 × Roma	6.18	1.01	0.97	-7.02	26.90	34.51	7.44	11.24
88572 × Roma	6.18	-2.00	3.57	-4.42	26.98	33.80	9.78	12.55
Rutgar Sala × Roma	-17.87	-25.21	-19.14	-28.66	23.33	25.33	2.30	2.44
017887 × Roma	-0.44	3.29	-0.75	0.40	5.30	10.68	-9.39	-4.45
CLN-2160 × Roma	-8.10	-3.59	-11.84	-12.66	-26.57	-19.20	-35.51	-29.67
CLN-2418 A × Roma	1.06	-1.04	-5.58	-11.03	43.76	54.18	34.67	52.56
Xi Yu-903 × Roma	11.47	5.85	-0.21	-10.11	-4.64	-9.69	-18.13	-25.19
Eden Oblong × Roma	-19.14	-23.73	-19.90	-26.44	-55.73	-45.54	-62.86	-53.96
TY-18 A × Pakit	-1.35	-7.85	-4.06	-8.30	19.42	25.62	13.19	25.32
BSX-717-1-1 × Pakit	1.32	15.39	0.37	12.66	8.97	11.56	-10.35	-4.01
UK × Pakit	-5.89	-8.71	-8.71	-8.81	9.41	16.69	-12.42	-3.52
CLN-5915-93-D-4-1-1-3 × Pakit	3.15	11.51	1.02	8.95	17.14	14.01	-7.61	-9.12
CLN-1744-23 × Pakit	8.27	18.39	8.04	16.71	44.91	53.77	21.36	32.08
017856 × Pakit	2.14	6.85	0.08	6.36	30.84	24.74	23.08	24.64
BSX-935-3-1-2 × Pakit	-1.14	-6.71	-8.21	-17.39	-26.07	-31.50	-28.07	-34.04
Samara Clauz Bonanza × Pakit	-7.56	-7.94	-10.28	-12.08	57.40	48.95	25.05	24.21
017904 × Pakit	-0.34	-11.42	-1.12	-17.68	26.18	18.06	16.05	8.91
017890 × Pakit	7.17	6.73	5.95	6.04	35.33	42.74	8.99	17.66
STD-552 × Pakit	-0.75	-8.24	-5.29	-12.24	-11.26	-8.79	-28.82	-26.66
88572 × Pakit	6.24	5.86	4.02	4.24	34.76	40.86	10.20	15.11
Rutgar Sala × Pakit	0.56	9.34	-0.63	8.53	19.15	17.55	4.62	-1.10
017887 × Pakit	7.25	21.99	6.51	20.52	29.43	42.35	5.39	19.25
CLN-2160 × Pakit	-5.18	-6.67	-8.71	-12.23	-28.38	-22.79	-40.58	-34.80

CLN-2418 A × Pakit	6.56	2.49	-0.08	-4.36	14.82	1.35	14.69	-3.20
Xi Yu-903 × Pakit	12.03	12.03	0.63	-1.52	-46.07	-46.94	-56.18	-57.27
Eden Oblong × Pakit	1.26	8.00	0.68	7.57	28.98	38.42	2.60	13.66

Table 9. Heterotic manifestation in hybrids for fruit firmness at pink class stage.

Crosses	Fruit firmness at pink class stage			
	Heterosis		Better parent heterosis	
	Faisalabad	Sialkot	Faisalabad	Sialkot
TY-18 A × Nagina	-24.76[a]	-25.63[b]	-33.11	-32.94
BSX-717-1-1 × Nagina	8.25	7.90	5.29	1.01
UK × Nagina	-14.34	-17.52	-17.41	-19.66
CLN-5915-93-D-4-1-1-3 × Nagina	-6.08	-3.90	-15.70	-12.94
CLN-1744-23 × Nagina	-20.27	-12.88	-20.41	-15.29
017856 × Nagina	-4.89	-4.98	-17.06	-16.64
BSX-935-3-1-2 × Nagina	0.64	4.97	-5.14	3.43
Samara Clauz Bonanza × Nagina	21.02	17.75	12.97	10.92
017904 × Nagina	19.43	23.63	15.36	19.16
017890 × Nagina	-20.34	-16.24	-20.88	-16.81
STD-552 × Nagina	-12.48	-16.53	-14.61	-18.66
88572 × Nagina	11.84	12.99	7.94	8.70
Rutgar Sala × Nagina	-13.61	-17.93	-18.77	-23.87
017887 × Nagina	1.43	-4.79	-5.06	-11.87
CLN-2160 × Nagina	10.20	19.22	2.03	15.64
CLN-2418 A × Nagina	20.28	12.10	17.41	12.10
Xi Yu-903 × Nagina	2.54	-4.83	1.68	-5.77
Eden Oblong × Nagina	-5.00	-3.01	-19.91	-16.91
TY-18 A × Roma	-21.35	-20.80	-31.37	-30.25
BSX-717-1-1 × Roma	2.57	0.26	-2.29	-8.44
UK × Roma	3.81	-4.87	-1.96	-9.71
CLN-5915-93-D-4-1-1-3 × Roma	6.12	1.17	-6.54	-10.51
CLN-1744-23 × Roma	12.67	18.82	10.46	12.58
017856 × Roma	16.41	11.23	-0.33	-4.62
BSX-935-3-1-2 × Roma	11.77	16.68	7.55	15.29
Samara Clauz Bonanza × Roma	22.14	17.16	11.76	7.64
017904 × Roma	-20.03	-19.49	-24.35	-24.36
017890 × Roma	-10.12	-10.12	-11.44	-13.06
STD-552 × Roma	-10.10	-13.31	-10.39	-13.38
88572 × Roma	11.43	8.02	9.84	6.68
Rutgar Sala × Roma	19.15	15.39	9.80	4.46
017887 × Roma	9.03	5.05	4.17	-0.29
CLN-2160 × Roma	16.62	16.42	10.17	15.96
CLN-2418 A × Roma	19.66	8.91	14.38	6.05
Xi Yu-903 × Roma	-18.21	-18.54	-19.28	-19.90
Eden Oblong × Roma	-27.42	-26.54	-37.70	-35.61
TY-18 A × Pakit	23.71	20.44	6.49	6.42
BSX-717-1-1 × Pakit	17.03	19.44	9.81	9.47
UK × Pakit	-3.06	-0.59	-9.81	-5.30
CLN-5915-93-D-4-1-1-3 × Pakit	18.76	20.43	3.16	6.90
CLN-1744-23 × Pakit	9.51	14.6	5.70	8.99
017856 × Pakit	19.48	13.43	0.95	-2.41
BSX-935-3-1-2 × Pakit	9.12	15.53	6.65	14.61
Samara Clauz Bonanza × Pakit	42.81	39.43	28.80	28.57
017904 × Pakit	39.90	35.15	30.38	27.45
017890 × Pakit	13.54	15.87	10.13	12.52
STD-552 × Pakit	1.60	3.36	0.32	3.03
88572 × Pakit	-3.65	-1.03	-3.80	-2.64
Rutgar Sala × Pakit	-13.07	-12.90	-21.04	-20.87
017887 × Pakit	48.77	44.33	44.35	36.48
CLN-2160 × Pakit	27.58	30.73	22.38	29.70

CLN-2418 A × Pakit	-3.53	-6.40	-9.18	-8.51
Xi Yu-903 × Pakit	-8.14	-6.99	-10.76	-8.19
Eden Oblong × Pakit	17.16	17.09	1.93	2.28

fruit length and pericarp thickness. Genotype 18 was found most stable in both environments with highest performance (Fig. 2).

***Fruit width and fruit weight*:** Fruit size and weight are yield contributing traits and most important for marketable yield of tomato. Biplot result revealed that genotype 17 and 34 had maximum FW and FWi while genotype 62 depicted least performance for these traits in the environment of Faisalabad (Fig. 1). In the environment of Sialkot, highest performance was presented by genotype 17 and lowest by genotype 6 for FW and FWi traits (Fig. 2). Hence, genotype 17 proved to be the best and stable for both environments in two different years.

***Fruit setting percentage/plant & marketable fruit yield/plant*:** Genotype 71 portrayed larger OP distance represented maximum FSPPP and MFYPP in both environments of Faisalabad and Sialkot. While genotype 34 had least FSPPP and MFYPP in both environments for two seasons (Fig. 1 and 2)

***Fruit firmness*:** Maximum FF was showed by genotypes 18 in Faisalabad and genotype 75 in Sialkot. So, these two have maximum fruit firmness and have highest shelf life. While genotype 40 and 34 represented minimum fruit firmness in Faisalabad and Sialkot, respectively.

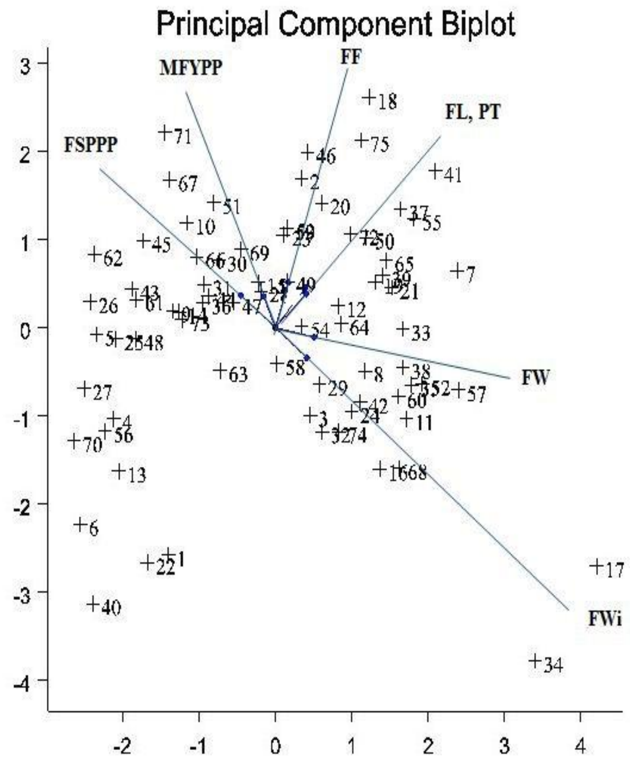

Figure 1. Biplot analysis representing the variation among parents and F_1 hybrids for fruit morphology traits in Faisalabad (2008 & 2012).

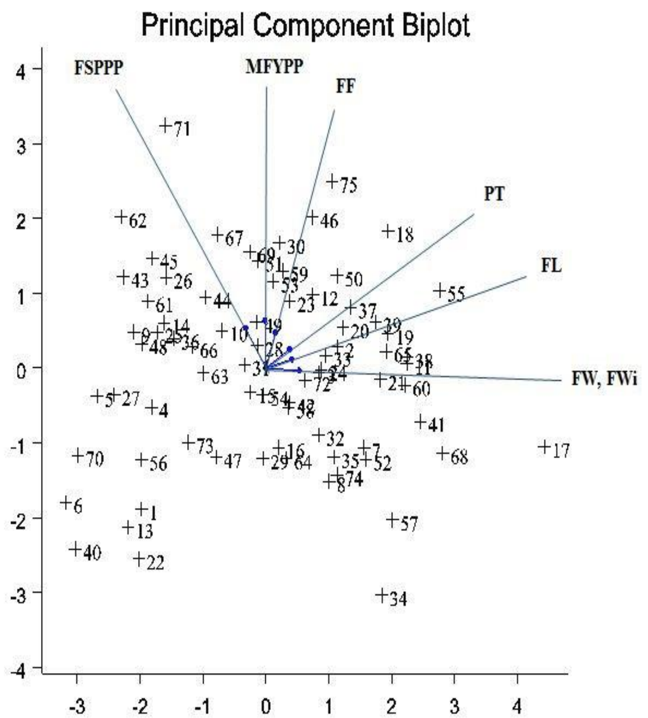

Figure 2. Biplot analysis representing the variation among parents and F_1 hybrids for fruit morphology traits in Sialkot (2008 & 2012).

FF = Fruit firmness at pink class stage, FSPPP = Fruit setting percentage/plant, MFYPP = Marketable fruit yield/plant, PT = Pericarp thickness, FL = Fruit length, FW = Fruit weight, FWi = Fruit width.

DISCUSSION

Tomato does not rank high in its nutritional value by virtue of the volume consumed although, it contributes to dietary intake of vitamin A, C as well as other essential minerals. The crop is being cultivated in almost all ecological zones of Pakistan. In Pakistan, tomatoes are grown on large areas with an average yield of 10-12 tonnes/ha (Anonymous, 2013-14). However, there is a huge gap between average tomato yield in Pakistan as compared to the world average (27.74 tonnes/ha) (Anonymous, 2014). This gap may be due to the lack of productive genetic resources. The tomato crop is vulnerable to both low and high temperature which severely hinders growth and fruit setting. Tomato crop is sensitive to chilling temperatures (0-12°C), therefore, its yield is affected by frost and low temperature (Dhaliwal and Chahal, 2005; Moustafa *et al*., 2006). So, high yields are obtained in the years whenever there is no frost during the growing period of tomato (Negi *et al*., 2012). The onset of frost and chilling temperatures during tomato growing season poses a big challenge for tomato breeders in the scenario when there is no frost/chilling tolerant varieties available for general cultivation (Moustafa *et al*., 2006; Negi *et al*., 2012). Therefore, there was need to develop frost-chilling tolerant/resistant hybrids coupled with improved yield potential in tomatoes. Keeping in view the above objective, the present study was planned to screen the available tomato germplasm against chilling temperatures and to work out the heterosis among the F_1 hybrids of selected frost tolerant and high yielding tomato parental genotypes for different important yield related traits.

In this study the presence of significant differences among the hybrids and lines for various yield related traits has emphasized the presence of variability among the hybrids and lines. It can be concluded that the improvement of yield and yield contributing characters including qualitative attributes in tomato can be accomplished through heterosis breeding. The presence of high heterosis indicated genetic diversity within the parental lines. Therefore, the hybrids those are capable enough to express better yield potential with acceptable qualitative performances at prescribed location as compared to the existing varieties could be used for commercial utilization. Significant variation for yield related traits has also been reported in previous studies (Govindarasu *et al.*, 1981; Siddiqui *et al.*, 2014). The existence of significant variation in the population for different yield related traits is the pre-requisite for improvement of yield in tomatoes. Selection made on the basis of different yield contributing traits has been reported for yield improvement in tomatoes (Pandey *et al.*, 2006; Siddiqui *et al.*, 2014). GGE biplot technique also proved that the studied genotypes and hybrids have greater genotypic and genotype × year interaction in multi-locations. Genotype × year interaction indicated in the biplot analysis suggests the necessity of further analysis to select the genotype that had high yield and stability across years. Close association between field performance and GGE biplot findings indicated that GGE biplot is a useful tool to graphically visualize the high-yielding and stable genotypes across years. The hybrids exhibiting more heterosis indicating improvement on fruit quality parameters like fruit firmness and also quantitative traits like fruit length, fruit width and fruit weight at both locations is possible with a significant manner through heterosis breeding. On the basis of comprehension about heterosis for different yield related traits, the genotype Roma is recommended to be used as male parent for hybridization for the improvement of maximum number of traits under study. This means that Roma has got a good genetic architecture which has been favoured in different genetic backgrounds while the female parent could be different for each trait to be improved. However, to increase marketable fruit yield per plant and fruit weight, cross combinations 017856 × Roma and CLN-2418 A × Roma respectively are recommended. In order to improve fruit setting percentage per plant and fruit width, cross combinations CLN-1744-23 × Nagina and Rutgar Sala × Nagina are the best choice among all the cross combinations being evaluated. It is obvious as Nagina is high yielding variety and has performed/enhanced the performance in the genetic backgrounds of CLN-1744-23 and Rutgar Sala.

Keeping in view the results of present study, convergent breeding programme involving different top F_1 hybrids for each trait, desired to be improved, is recommended for the improvement of yield and different yield traits with frost tolerant background in tomatoes. This is because for every trait there has been a specific combination and if all the desirable combinations for various economically as well as quality traits would combine together so, they can give a good performance by converging all the traits.

Conclusion**:** The novelty of the study comes from the screening of a wide array of tomato genotypes against the frost stress. The frost tolerant germplasm was tested in different genetic back grounds for making a meaningful inference. The diversity among the lines had a played a significant role in the manifestation of heterosis.

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