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GENETIC DIVERSITY ANALYSIS IN ELITE LINES OF TOMATO (*Solanum lycopersicum* L.) FOR GROWTH, YIELD AND QUALITY PARAMETERS

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To increase productivity in tomato, it is necessary to develop superior varieties/hybrids. This is, in part, dependent on variability in the genetic material which affects agro-morphological and biochemical characters in crop breeding. A study was conducted with 51 tomato genotypes and the standard checks/reference cultivars Punjab Upma, Punjab Chuhhara and Punjab Ratta to determine character association, path coefficient analysis and genetic diversity to select genotypes and traits for breeding. There were differences among genotypes for all characters indicating a high degree of variability in the material. Overall, highly significant, positive, correlation coefficients, as well as high direct effects of fruit weight and marketable yield on total fruit yield, indicated these traits are reliable components for selecting high fruit yielding tomato genotypes. The D^2 statistics confirmed the highest inter-cluster distance between clusters VI and VIII (27638.44). Maximum similarity was observed in clusters IV and VI (191.02). This indicated existence of the possibility to improve genotypes through hybridization from any pair of clusters and subsequent selection can be made from segregant generations.

*Key words: g*enetic diversity, genetic relationship, morphological traits, *Solanum lycopersicum* L.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a rich source of vitamins A, B_2, C, lycopene (antioxidant) and the minerals Ca, P, and Fe (COHEN *et al*., 2000; DHALIWAL *et al*., 2003;

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MARKOVIĆ, 2010; RIZVI *et al*., 2013). Agro-statistics include India as second highest tomato producers in the world after China. In 2014, the growing area reached 0.88 M ha, resulting in a total production of about 18.73 M tons (share about 11.5 % of the world tomato production) (FAO 2014). Even though there are commercial varieties available it is always necessary to examine genetic material that could either be more acceptable by consumers or more adapted to local climatic conditions. Genetic resources are the most valuable and essential basic raw material to meet the current and future needs for genetic improvement of any crop. Genetic variability is a pre-requisite for improving crops (GLOGOVAC *et al*., 2010; KAUSHIK *et al*., 2011). To bring about genetic improvement in segregating population, information regarding the nature and strength of association between yield and yield-related traits will identify selection efficiency (ASISH *et al*., 2008; IJAZ *et al*., 2015).

The genetic diversity of selected plants is not always based on geographical diversity or place of release. Characterization of genetic divergence for selection of suitable and diverse genotypes should be based on sound statistical procedures. The generalized D^2 statistic, devised by MAHALANOBIS (1936), is a powerful technique to identify diverse groups in any material. These procedures characterize genetic divergence using the criterion of similarity or dissimilarity based on the aggregate effect of a number of economically important characters.

The investigation was undertaken to assess the nature of variability, heritability and genetic advance, and to determine the nature of association of different fruit quality parameters on fruit and among themselves through correlation and path analysis with genetic diversity analysis.

MATERIAL AND METHODS

The experimental material comprised of 51 genotypes introduced from the Asian Vegetable Research and Development Centre, The World Vegetable Centre, Shanhua, Tainan, Taiwan, and the check of cultivars/ reference cultivars 'Punjab Upma, 'Punjab Chuhhara' and 'Punjab Ratta'. The plants were grown at the Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana, Punjab (India). The experiment was arranged in a randomized complete block design with 3 replications. The experimental field is situated at 30^o 55’ north latitude, 75^o 54’ east longitude at an altitude of 247 m above sea level. The area forms a part of the Indo-Gangetic alluvial plains and the soil was a sandy loam.

The field was first ploughed with soil turning plough followed by 3 ploughing with harrow after that proper leveling was done. Twenty four metric tons of cow manure and N: P: K (from urea, single superphosphate and muriate of potash, respectively) fertilizer, 148:61:61 $kg \cdot ha^{-1}$, respectively, was applied to the soil (ANONYMOUS, 2010). Half of the N and all of the manure, P and K were applied before the final plowing and leveling of the field. The other half quantity of N was applied as top dressing after 30 days of transplanting. Weeding was done as at when required. Irrigation water was applied at 7 to 15 days intervals from transplanting to final harvest. Seed were sown on well prepared nursery beds (7.0m × 1.5m × 20cm in length, width and height) during the third week of October. Before sowing, the seed beds were drench with 1.5% solution of Formalin by applying 4-5 litres of solution per square meter. Soon after the beds were covered with plastic sheet for 48 hours. For raising good and healthy seedlings, seeds were treated with fungicide Captan (in powder form) at the rate of $2g \cdot kg^{-1}$ seed. Seeds were sown 1 to 2 cm deep in lines with 5 cm spacing. The nursery plants were drenched,with 0.4% Captan after 7 days of germination. Seedlings were transplanted in the last week of November 2010 and plants were protected from frost in the field by covered with polythene sheets (low tunnel). Each entry consisted of a single row comprised of ten plants with a row spacing of 120 cm and plant spacing of 30 cm.

Observation were from 5 randomly selected plants per replication for each genotype on the quantitative and qualitative characters *viz.* plant height (cm); days to flower initiation; days to first harvest; marketable yield per plant (kg); total fruit yield per plant (kg); fruit weight (g); number of locules; pericarp thickness (mm); fruit shape index; total soluble solids (°Brix); dry matter (%); ascorbic acid content (mg/100 ml of juice); titrable acidity (mg/100 ml of juice); lycopene content (mg/100 g of fresh weight); and carotene content (mg/100 g of fresh weight).

Analysis of variance was with the method of PANSE and SUKHATME (1985). The genotypic and phenotypic correlation coefficients were calculated as per AL-JIBOURI *et al.* (1958). Path coefficients were obtained following the method of DEWEY and LU (1959). Multivariate analysis was with the Mahalanobis D^2 statistic (MAHALANOBIS, 1936) and genotypes grouped into clusters following Tocher's method (RAO, 1952).

RESULTS AND DISCUSSION

Values for characters studied in tomato varied (Table 1, 2). The genotype 'CLN 3024-F_2-104-48-1-0' had the highest total and marketable fruit yields. The genotype 'CLN 2418 A' had the best fruit weight followed by 'LBR 10'. The highest total soluble solid was in 'LBR 19', followed by 'LBR 13'. The highest lycopene content was in genotype 'CLN 2366 A', followed by 'CLN 2679 E' and 'CLN 1314 G'. The genotype 'EC 654789' had the greatest ascorbic acid content, followed by 'EC 654768'. Genotypes 'CLN 3024-F_2-104-48-1-0' and 'CLN 3008-F_2-132-17-10-0' bore flowers early. The thickest pericarp was in fruit of 'LBR 19'. Genotype 'CA 2' had the fewest number of locules per fruit. The tallest plants were for genotype 'CLN 1314 G', followed by 'EC 654760' and 'CLN 1462 B'. The highest titrable acidity was in 'LBR 19', 'CLN 2026 D' and 'LBR15'. The highest dry matter was in 'CLN 3022-F_2-37-8-1', followed by 'EC 15988'. Genotype 'CLN 2777-F-18-9' had the greatest carotene content.

Table 1. Mean performance of tomato genotypes for quantitative traits

Genotype	Plant height (cm)	Days to flower initiation	Days to first harvest	Marketable yield (kg/plant)	Total fruit yield (kg/plant)	Fruit weight (g)	Pericarp thickness (mm)	No. locules	Fruit shape index
Ty52	66.00	39.00	146.33	1.10	1.33	50.02	5.07	1.89	1.22
FLA 456-4	102.33	43.33	147.00	1.08	1.18	54.76	4.27	5.03	1.18
CA 2	63.00	54.00	141.00	1.11	1.19	59.44	6.84	1.82	0.97
CA 4	114.00	48.33	148.67	1.65	1.71	77.04	6.70	3.97	1.16
CLN 2679E	109.00	48.67	140.00	1.65	1.84	99.34	7.42	4.60	1.18
CLN 2679F	56.67	45.67	140.00	0.64	0.85	82.76	5.33	3.97	1.05
CLN 2714G	66.67	49.00	140.33	1.17	1.21	87.00	2.79	4.66	0.99
CLN 2714H	74.00	46.67	141.00	1.15	1.22	88.96	3.96	6.87	0.78
CLN 2714J	113.33	51.33	149.33	0.68	0.70	91.98	3.12	5.15	0.97
CLN 2585C	60.67	52.33	149.33	1.57	1.59	74.43	5.93	3.49	1.19
EC 654760	136.67	37.67	140.33	2.38	2.40	29.43	4.17	2.39	1.10
LBR 9	96.00	46.00	140.33	1.68	1.86	109.32	4.13	3.30	0.87
LBR 10	83.33	55.00	149.00	1.69	1.72	111.99	5.96	2.94	0.91
LBR 11	107.33	63.33	149.67	1.84	1.85	140.01	5.87	3.08	0.93
LBR 16	88.33	39.00	150.67	1.75	1.79	110.08	4.79	4.91	0.88
LBR 17	94.33	61.67	141.00	2.00	2.05	236.89	5.30	3.19	0.83
CLN 2413R	107.67	41.00	140.67	2.19	2.60	91.93	3.04	5.05	1.00
CLN 1621L	60.33	44.00	148.00	1.84	2.23	49.41	5.34	3.94	0.89
CLN 2366A	95.67	62.33	150.00	2.45	2.48	49.48	5.09	2.09	1.17
CLN 2366B	68.00	61.67	149.67	1.89	1.94	38.83	4.91	2.12	0.99
CLN 2366C	120.33	52.00	147.00	1.86	1.94	99.50	4.78	3.83	0.87
CLN 1314G	142.67	44.33	150.33	2.25	2.32	81.76	6.25	3.50	0.86
CLN 1460A	62.00	44.33	141.00	2.10	2.19	103.73	6.16	3.69	0.89

CLN 1462A	76.33	45.33	143.00	2.24	2.31	99.44	4.73	4.70	1.01
CLN 1462B	136.00	50.00	149.00	2.47	2.55	93.13	4.94	4.23	0.88
CLN 1464A	85.67	63.00	149.67	2.11	2.19	92.10	3.86	4.98	0.87
CLN 1464B	57.00	62.00	147.00	1.50	1.55	69.36	6.22	3.07	1.18
CLN 2123C	78.00	43.00	139.67	2.10	2.24	56.83	6.47	2.04	1.39
CLN 2123D	65.67	50.00	150.00	1.71	1.86	66.80	5.91	2.02	1.27
CLN 3022- F_2-37-8-1	121.67	38.00	150.00	1.89	2.11	71.89	7.66	2.53	1.14
CLN 3022- F_2-37-29-8-0	81.33	38.33	149.67	1.29	1.46	61.82	7.59	2.04	1.18
CLN 3010- F_2-76-9-13-0	71.67	45.00	149.67	2.15	2.35	61.85	4.82	3.02	1.01
CLN 3022- F_2-138-6-2-0	81.67	39.33	150.67	2.46	2.55	39.66	4.69	2.22	1.22
CLN 3022- F_2-138-6-7-0	96.00	44.00	150.00	2.04	2.68	49.47	6.11	3.04	1.09
CLN 3024- F_2-104-48-1-0	71.33	34.00	141.00	2.76	2.82	62.44	6.24	2.22	1.27
CLN 3022- F_2-154-11-11-0	66.33	63.33	149.67	0.90	1.05	36.74	5.01	2.15	1.23
CLN 3008- F_2-132-17-10-0	84.67	36.33	150.33	1.90	2.05	84.32	7.15	5.04	1.12
CLN 2777-F-18-9	118.67	60.33	162.33	1.34	1.40	61.94	5.01	2.95	0.94
LBR 19	65.67	65.33	163.33	1.34	1.42	107.80	7.92	4.24	0.82
CLN 2026D	60.00	38.67	141.67	1.49	1.96	69.43	6.62	3.93	1.09
EC 654789	120.33	37.67	149.67	2.02	2.13	99.32	5.10	4.54	0.88
EC 654768	116.00	46.00	149.67	1.48	1.57	71.82	4.57	4.63	0.97
CLN 2418 A	56.33	45.67	149.00	1.76	1.79	112.11	6.95	5.97	1.24
CLN 2366 C-1	99.00	49.67	148.67	2.33	2.44	59.94	4.81	6.23	0.83
EC 15988	127.00	45.33	150.33	1.78	1.97	44.46	5.74	2.28	0.98
EC 11975	84.67	45.33	141.67	2.29	2.33	55.78	4.97	4.85	0.88
LBR 12	84.67	44.33	142.00	2.10	2.19	155.78	6.88	3.45	0.85
CLN 5915-206 D4	81.67	47.67	146.00	1.10	1.21	64.68	4.78	3.16	1.00
LBR13	66.67	45.67	150.67	1.90	1.96	82.59	3.94	5.08	0.79
LBR 15	95.00	45.00	162.33	1.64	1.75	99.41	5.60	3.28	0.76
EC 531802	126.00	45.33	151.00	1.89	1.93	65.79	3.50	4.25	0.82
PunjabChuhhara (check)	106.67	45.67	148.67	1.96	2.12	77.69	6.18	4.03	1.73
Punjab Ratta (check)	94.67	49.00	151.33	2.05	2.29	86.97	6.49	3.27	1.24
Punjab Upma (check)	88.67	49.00	143.00	1.95	1.97	76.28	5.78	3.18	0.87
General Mean	90.49	48.11	147.43	1.77	1.90	80.66	5.43	3.67	1.03
Range	56.33-142.67	34.00-65.33	139.67-163.33	0.64-2.76	0.70-2.82	29.43-236.89	2.79-7.92	1.82-6.87	0.76-1.73
CD (5%)	16.37	8. 01	4.09	0.08	0.08	1.21	0.94	0.72	0.09

Table 2. Mean performance of tomato genotypes for quality traits.

Genotype	Dry matter (%)	Total soluble solid (°Brix)	Titrable acidity (g /100 ml juice)	Lycopene Content (mg/100g of fresh weight)	Ascorbic acid (mg/100 ml juice)	Carotene content (mg/100 g fresh weight)
Ty52	4.18	4.37	0.72	0.96	26.01	0.31
FLA 456-4	4.29	3.90	0.70	2.56	60.54	1.64
CA 2	4.01	2.47	0.52	1.54	27.03	0.98
CA 4	3.79	3.50	0.49	1.12	25.96	0.37
CLN 2679E	3.86	2.50	0.35	3.78	57.60	0.63
CLN 2679F	4.31	3.53	0.56	0.62	56.39	1.43
CLN 2714G	2.49	3.73	0.49	1.11	72.55	0.85
CLN 2714H	3.96	4.73	0.90	0.57	70.66	0.73
CLN 2714J	3.73	3.40	0.87	1.19	45.86	0.08
CLN 2585C	3.85	2.27	0.45	0.39	51.59	0.35
EC 654760	4.17	4.33	0.80	0.54	68.86	0.04
LBR 9	4.00	3.63	0.57	2.13	25.37	0.67
LBR 10	3.70	4.47	0.85	0.83	47.60	0.04
LBR 11	4.54	4.63	0.54	2.99	42.73	0.59
LBR 16	3.69	4.27	0.83	2.84	53.15	0.60
LBR 17	3.07	4.47	0.38	3.54	17.15	0.82
CLN 2413R	3.85	3.77	0.59	3.18	57.17	1.36
CLN 1621L	3.37	2.30	0.66	0.75	66.37	1.24
CLN 2366A	3.42	3.73	0.74	3.95	56.18	0.37
CLN 2366B	4.36	4.07	0.44	0.90	76.47	1.43
CLN 2366C-1	3.79	3.33	0.76	0.52	40.12	0.06
CLN 1314G	4.08	3.37	0.58	3.70	66.26	1.33
CLN 1460A	3.76	2.13	0.36	2.90	40.46	0.19
CLN 1462A	4.27	2.77	0.49	3.28	28.24	1.03
CLN 1462B	4.36	3.50	0.79	3.40	56.46	1.27
CLN 1464A	2.14	2.13	0.55	1.07	56.31	1.31
CLN 1464B	3.19	3.63	0.36	3.38	40.66	0.89

CLN 2123C	4.36	3.27	0.71	1.25	71.37	0.35
CLN 2123D	4.58	2.20	0.85	2.73	72.18	1.11
CLN 3022- F_2-37-8-1	4.83	1.47	0.53	1.27	51.44	1.34
CLN 3022- F_2-37-29-8-0	4.66	2.73	0.65	2.63	34.39	0.84
CLN 3010- F_2-76-9-13-0	4.17	3.83	0.57	0.85	26.41	1.37
CLN 3022- F_2-138-6-2-0	3.58	3.87	0.56	2.93	33.06	1.45
CLN 3022- F_2-138-6-7-0	3.60	3.70	0.45	3.42	45.41	1.33
CLN 3024- F_2-104-48-1-0	3.80	4.20	0.53	3.32	71.12	1.35
CLN 3022- F_2-154-11-11-0	3.70	3.37	0.77	3.06	26.37	1.64
CLN 3008- F_2-132-17-10-0	2.90	2.10	0.60	0.90	66.34	0.48
CLN 2777-F-18-9	4.56	4.13	0.62	3.54	10.44	1.72
LBR 19	4.30	5.40	0.96	0.78	51.80	0.03
CLN 2026D	4.26	2.13	0.96	0.51	55.74	0.03
EC 654789	3.81	3.70	0.95	0.85	82.27	0.19
EC 654768	2.06	2.70	0.77	2.18	77.12	1.45
CLN 2418 A	2.14	1.47	0.76	0.86	75.02	0.13
CLN 2366 C	4.43	3.03	0.86	2.00	41.13	1.25
EC 15988	4.82	4.73	0.77	3.66	41.14	1.01
EC 11975	4.15	3.77	0.80	3.30	35.57	1.23
LBR 12	3.99	3.93	0.70	0.99	43.67	0.37
CLN 5915-206 D4	4.61	4.80	0.61	3.18	36.86	0.89
LBR13	4.71	5.00	0.50	0.74	47.58	0.65
LBR 15	4.23	4.97	0.96	0.77	52.75	0.60
EC 531802	4.07	3.83	0.93	1.42	66.36	0.09
PunjabChuhhara (check)	3.68	4.63	0.84	2.71	53.51	0.57
Punjab Ratta (check)	3.54	3.60	0.63	2.34	30.53	1.14
Punjab Upma (check)	3.61	3.30	0.68	1.51	41.51	0.90
General Mean	3.88	3.53	0.66	1.99	49.54	0.82
Range	2.06-4.83	1.47-5.40	0.35-0.96	0.39-3.95	10.44-82.27	0.03-1.72
CD (5%)	0.58	0.84	0.10	0.35	7.20	0.43

There were differences among genotypes for all characters indicating a high degree of variability in the material. Similar results were reported by SINGH and CHEEMA (2005); BASAVARAJ *et al*. (2010); KAUSHIK *et al*. (2011), and DAR and SHARMA (2011) in tomato.

The range of mean values based on phenotypic expression represents a rough estimate of variation or magnitude of divergence among genotypes. The phenotypic and genotypic coefficients of variation varied (Fig. 1). A relative amount of variation in genotypes for characters can be judged by comparing the coefficient of genotypic and phenotypic variations. Estimates of the phenotypic coefficient of variation (PCV) were higher than genotypic coefficient of variation (GCV) for all traits indicating the additive effect of environment on expression of a trait. Similar finding were reported by DAR and SHARMA (2011); GOLANI *et al*. (2007); KAUSHIK *et al*. (2011); RANI and ANITHA (2011), and CHERNET *et al*. (2013) in tomato. There were narrow differences between phenotypic and genotypic coefficients of variation in all characters indicating a low environmental influence in expression, implying phenotypic variability is a reliable measure of genotypic variability. Selection for improvement of the traits is possible and effective on the phenotypic basis (MEENA and BAHADUR, 2014). Higher magnitudes of GCV and PCV occurred for carotene content, followed by lycopene content, fruit weight, ascorbic acid, number of locules, marketable yield, plant height, total fruit yield, titrable acidity, TSS, and pericarp thickness. These results indicated that traits with higher magnitudes of coefficient of variation offer a better opportunity for improvement through selection (HEDAU *et al*., 2008; MEENA and BAHADUR, 2014).

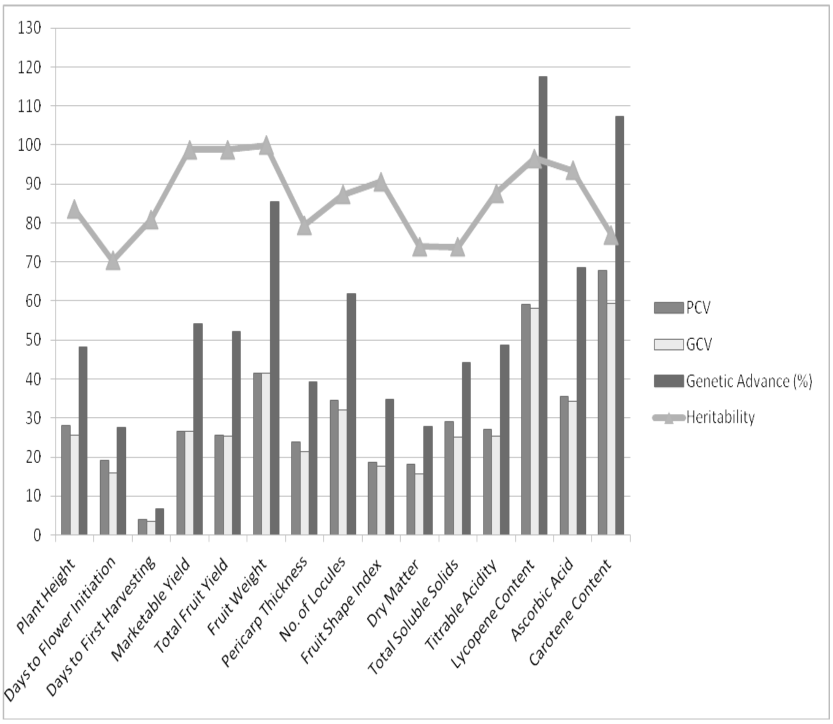

Figure 1. Graphical representation of genetic parameters

Selection is favored when a major proportion of a large amount of phenotypic variability is due to heritable variation. In the present study, all characters had high heritability, the magnitude of heritability indicating these traits are controlled by additive gene action. High heritability was recorded for ascorbic acid, TSS, lycopene, and pericarp thickness by HEDAU *et al*. (2008); KUMAR *et al*. (2001), ARA *et al*. (2009). SINGH *et al*. (2000) reported high heritability for fruit yield, days to first harvest, fruit weight, days to first flowering and plant height. MEENA and BAHADUR (2014) reported high heritability for all studied characters.

There was a wide range of the estimate of genetic advance for titrable acidity and fruit weight. In this study, all characters exhibited high genetic advance expressed as percent of mean except days to first harvest and exhibited a wide range. These findings agree with SINGH *et al*. (2001); JOSHI *et al*. (2004), and ARA *et al*. (2009). Traits having high estimates of heritability, coupled with high genetic advance, may help establish the close relationship between genotypes and phenotypes (BURTON and DE VANE, 1953). This was evident in the present investigation in that fruit weight, lycopene content, total fruit yield, marketable yield, ascorbic acid and number of locules accounted higher heritability as well as higher genetic advance. These characters can be improved by selection methods (ARA *et al*. 2009; MEENA and BAHADUR, 2014).

It is necessary to understand the importance of genetic correlation, as this provides valuable information regarding the correlated response to selection (MEENA and BAHADUR, 2015). The genotypic coefficient of correlations in general was higher in magnitude than corresponding phenotypic coefficient of correlations (Table 3). This indicates there was an inherent association among various characters and phenotypic expression of correlation was lessened under the influence of environment. The results corroborated those of GOLANI *et al*. (2007); ARA *et al*. (2009); ISLAM *et al*. (2010); DAR *et al*. (2011), KUMARI and SHARMA (2013).

Total fruit yield per plant was positively, and significantly, correlated with lycopene content, plant height, fruit weight and marketable yield. This indicated these characters can be considered as indicators of higher total fruit yield per plant and crop improvement may be best achieved by improvement in these 4 characters. These findings agree with SUSIC *et al*. (2002) for fruit weight; ARA *et al*. (2009) for fruit weight and plant height, and RANI *et al*. (2010) for fruit weight and lycopene content. Total fruit yield per plant had a negative, significant, correlation with days to flower initiation.

Fruit weight was positively, and significantly, correlated with number of locules, total fruit yield and days to flower initiation as was reported by RANI *et al*. (2010); ARA *et al*. (2009) for fruit yield per plant, and KUMARI and SHARMA (2013) for fruit yield per plant and days to first flowering. The results indicated that selection for fruit weight can favor selection of plants with higher fruit yield per plant, more number of locules and early flower initiation. Marketable yield per plant was positively, and significantly correlated with lycopene content, plant height and total fruit yield, indicated that as the marketable yield increases, lycopene content, plant height and total fruit yield would also increase. Days to first harvest were positively correlated with TSS, titrable acidity, days to flower initiation, indicating least days to harvesting after transplanting can be favor higher TSS, titrable acidity and early flowering.

Positive, significant, associations of total soluble solids with days to first harvest, dry matter, and acidity, and significant, negative, correlations with pericarp thickness and fruit shape index occurred. The results indicating that as the TSS increases, positively associated traits would also increase, and negatively associated traits would decrease.

Titrable acidity exhibited significant, positive, correlations with number of locules, TSS, ascorbic acid, plant height and days to first harvest which was reported by RANI *et al*. (2010) for ascorbic acid; there was a negative, significant, correlation with lycopene content and carotene content. Ascorbic acid was positively and significantly correlated with number of locules and titrable acidity; there was a negative, significant, correlation with lycopene content, dry matter, days to flower initiation. Significant, negative, correlation of ascorbic acid with days to first flowering was reported by KUMARI and SHARMA (2013). Lycopene content was positively correlated with fruit shape index, carotene content, plant height, marketable yield and total fruit yield. Because these association traits were in the desirable direction, selection for these traits may improve lycopene content in tomato fruits. This agreed with findings of RANI *et al*. (2010) for yield per plant and DAR *et al*. (2011) for carotene content and fruit yield per plant. Carotene content was positively, and significantly correlated with lycopene content. The significant, positive, associations among characters indicate there is the possibility of improvement in the traits which influence each other (ARA *et al*., 2009).

Table 3. Genotypic (G) and Phenotypic (P) correlation coefficient of 15 characters in tomato.

Character	Pericarp thickness	No. locules	Fruit shape index	Total soluble solids	Titrable acidity	Ascorbic acid	Lycopene content	Carotene content	Dry matter	Plant height	Marketable yield	Total fruit yield	Days to first harvest	Days to flower initiation
No. locules	P -0.2856													
	G -0.3380**													
Fruit shape index	P 0.2990	-0.3122												
	G 0.3454**	-0.3545**												
Total soluble solids	P -0.2165	-0.0610	-0.1886											
	G -0.3347**	-0.1050	-0.2183**											
Titrable acidity	P -0.1049	0.2060	-0.1064	0.1895										
	G -0.1310	0.2212**	-0.1298	0.2348**										
Ascorbic acid	P -0.0551	0.2625	0.0674	-0.1411	0.2634									
	G -0.0787	0.2928**	0.0702	-0.1823	0.2949**									
Lycopene content	P 0.0223	-0.1896	0.1632	0.0895	-0.2643	-0.2756								
	G 0.0384	-0.2043**	0.1752*	0.1110	-0.2977**	-0.2913**								
Carotene content	P -0.1287	-0.0952	0.0485	-0.0148	-0.3052	-0.1272	0.4027							
	G -0.1899	-0.1077	0.0459	-0.0940	-0.3409**	-0.1458	0.4677**							
Dry matter	P 0.1284	-0.2637	-0.0640	0.2814	0.1501	-0.2163	0.0816	0.0408						
	G 0.1321	-0.3440**	-0.0629	0.3364**	0.1209	-0.2665**	0.0879	0.0611						
Plant height	P -0.1335	0.0346	-0.1367	0.1507	0.1894	0.0294	0.2568	0.0267	0.1155					
	G -0.1772	0.0707	-0.1553	0.1652	0.2169**	0.0478	0.2722**	0.0073	0.1669					
Marketable yield	P 0.0450	-0.0685	-0.0025	-0.0305	-0.0938	0.1255	0.2574	0.0459	-0.0397	0.2626				
	G 0.0566	-0.0646	-0.0123	-0.0365	-0.0999	0.1297	0.2618**	0.0516	-0.0459	0.2883**				
Total fruit yield	P 0.0844	-0.0768	0.0366	-0.0758	-0.1009	0.1200	0.2583	0.0924	-0.0107	0.2300	0.9623			
	G 0.0919	-0.0880	0.0367	-0.0869	-0.1114	0.1211	0.2630**	0.1068	-0.0282	0.2611**	0.9701**			
Days to first harvest	P 0.1404	-0.0428	-0.1040	0.2052	0.2724	-0.0759	-0.0200	0.0644	0.0654	0.1665	-0.0695	-0.0865		
	G 0.1452	-0.0543	-0.1123	0.2208**	0.3350**	-0.0860	-0.0263	0.0529	0.1223	0.1879	-0.0721	-0.0934		
Days to flower	P -0.0086	-0.1167	-0.1466	0.0650	-0.1435	-0.2532	0.1069	0.0553	-0.0799	-0.0809	-0.2084	-0.2747	0.1968	
initiation	G -0.0172	-0.1352	-0.1933	0.1827	-0.1594	-0.3137**	0.1374	0.0753	-0.1560	-0.1691	-0.2451**	-0.3290**	0.2943**	
Fruit weight	P 0.0865	0.2668	-0.3512	0.0953	-0.1112	-0.1409	0.0089	-0.2779	-0.2019	0.0386	0.0424	0.1380	-0.1005	0.1779
	G 0.0961	0.2862**	-0.3673**	0.1100	-0.1191	-0.1460	0.0091	-0.3167**	-0.2353**	0.0413	0.0429	0.1350*	-0.1111	0.2142**

*, ** significant at 5 % or 1 % levels of significance

Table 4: Direct indirect effects of characters on yield per plant at genotypic (G) and phenotypic (P) levels in tomato.

Character	Pericarp thickness	No. locules	Fruit shape index	Total soluble solids	Titrable acidity	Ascorbic acid	Lycopene content	Carotene content	Dry matter	Plant height	Marketable yield	Fruit weight	Days to first harvest	Days to flower initiation
Pericarp thickness	**G 0.0480[a]**	0.0074	-0.0031 -	0.0020	-0.0022	0.0027	-0.0002	-0.0139	-0.0041	0.0026	0.0535	-0.0017	-0.0011	0.0020
	P 0.0441	-0.0032	0.0008	0.0071	-0.0009	0.0010	0.0002	-0.0063	0.0021	0.0024	0.0427	-0.0027	-0.0019	0.0006
No. locules	G -0.0162	**-0.0218**	0.0032	0.0006	0.0037	-0.0100	0.0010	-0.0079	0.0107 -	-0.0010	-0.0610	-0.0051	0.0004	0.0155
	P -0.0126	**0.0113**	0.0008	0.0020	0.0018	-0.0047	-0.0013	-0.0046	0.0044	-0.0006	-0.0650	-0.0083	0.0006	0.0084
Fruit shape index	G 0.0166	0.0077-	**-0.0089 -**	0.0013	-0.0022	-0.0024	-0.0009	0.0034	0.0020 -	0.0023	-0.0117	0.0066	0.0008	0.0221
	P 0.0132	0.0035	**0.0025**	0.0062	-0.0009	-0.0012	0.0011	0.0024	0.0011	0.0024	-0.0024	0.0110	0.0014	0.0105
Total soluble solids	G -0.0161	0.0023	0.0020	**-0.0060**	0.0040	0.0062	-0.0005	-0.0069	-0.0105	-0.0024 -	-0.0344	-0.0020	-0.0016	-0.0209
	P -0.0095	-0.0007	0.0005	**-0.0327**	0.0016	0.0025	0.0006	-0.0007	0.0047	0.0027	-0.0289	-0.0030	-0.0028	-0.0047
Titrable acidity	G-0.0063	-0.0048	0.0012	-0.0014	**0.0169**	-0.0101	0.0014	-0.0249	-0.0038	-0.0032	-0.0944	0.0021	-0.0025	0.0183
	P -0.0046	0.0023	0.0003	-0.0062	**0.0086**	-0.0047	-0.0019	-0.0149	0.0025	-0.0034	-0.0891	0.0035	-0.0037	0.0103
Ascorbic acid	G -0.0038	-0.0064	-0.0006 -	0.0011	0.0050	**-0.0342**	0.0014	-0.0106	0.0083 -	-0.0007 -	0.1225	0.0026	0.0006	0.0359
	P-0.0024	0.0030	0.0002	0.0046	0.0023	**-0.0178**	-0.0019	-0.0062	0.0036	0.0005	0.1192	0.0044	0.0010	0.0182
Lycopene content	G 0.0018	0.0045 -	-0.0016 -	-0.0007	-0.0050	0.0100	**-0.0049**	0.0342	-0.0027	-0.0040	0.2472	-0.0002	0.0002	-0.0157
	P 0.0010	0.0021	0.0004	-0.0029	-0.0023	0.0049	**0.0070**	0.0196	0.0014	-0.0046	0.2445	-0.0003	0.0003	-0.0077
Carotene content	G -0.0091	0.0023-	-0.0004	0.0006	-0.0058	0.0050	-0.0023	**0.0730**	-0.0019	-0.0001 -	0.0487	0.0057	-0.0004	-0.0086
	P -0.0057	0.0011	-0.0001	0.0005	-0.0026	0.0023	0.0028	**0.0487**	0.0007	0.0005	0.0436	0.0087	-0.0009	-0.0040
Dry matter	G 0.0063	0.0075	0.0006	-0.0020	0.0020	0.0091	-0.0004	0.0045	**-0.0312**	-0.0025 -	-0.0433	0.0042	-0.0009	0.0179
	P 0.0057	-0.0030	0.0002	-0.0092	0.0013	0.0039	0.0006	0.0020	**0.0165**	0.0021	-0.0377	0.0063	-0.0009	0.0057
Plant height	G -0.0085	-0.0015	0.0014	-0.0010	0.0037	-0.0016	-0.0013	0.0005	-0.0052	**-0.0148 -**	0.2722	-0.0007	-0.0014	0.0194
	P -0.0059	0.0004	0.0003	-0.0049	0.0016	-0.0005	0.0018	0.0013	0.0019	**0.0179**	0.2495	-0.0012	-0.0022	0.0058
Marketable yield	G 0.0027	0.0014 -	0.0001	0.0002	-0.0017	-0.0044	-0.0013	0.0038	0.0014 -	-0.0043 -	**0.9442**	-0.0008	0.0005	0.0281
	P 0.0020	0.0008	0.0000	0.0010	-0.0008	-0.0022	0.0018	0.0022	0.0007	0.0047	**0.9499**	-0.0013	0.0009	0.0150
Fruit weight	G 0.0046	-0.0062	0.0033	-0.0007	-0.0020	0.0050	0.0000	-0.0231	0.0073 -	-0.0006 -	0.0405	**0.0179**	0.0008	-0.0245
	P 0.0038	0.0030	0.0009	-0.0031	-0.0010	0.0025	0.0001	-0.0135	0.0033	0.0007	0.0403	**0.0313**	0.0014	-0.0128
Days to first harvest	G 0.0070	0.0012 -	0.0010	-0.0013	0.0057	0.0029	0.0001	0.0039	-0.0038	-0.0028 -	-0.0681	0.0020	**-0.0074**	-0.0337
	P 0.0062	0.0005	0.0003	-0.0067	0.0023	0.0014	-0.0001	0.0031	0.0011	0.0030	-0.0660	0.0031	**-0.0135**	-0.0142
Days to flower initiation	G -0.0008	0.0030 -	0.0017	-0.0011	-0.0027	0.0107	-0.0007	0.0055	0.0049 -	0.0025	-0.2314	-0.0038	-0.0022	**-0.1146**
	P -0.0004	0.0013	0.0004	-0.0021	-0.0012	0.0045	0.0008	0.0027	0.0013	0.0014	-0.1980	-0.0056	-0.0027	**-0.0719**

Explained variation: (P) 0.940, (G) 0.959: Unexplained variation: (P) 0.060 (G) 0.041; Bold figures indicate direct effects.

In the present study genotypic, and phenotypic, correlation coefficients were partitioned into direct and indirect effects (Table 4). The estimates indicated that marketable yield had the highest positive direct effect on total fruit yield followed by carotene content, pericarp thickness, fruit weight and titrable acidity, indicated that these traits would improve total fruit yield.

These results agree with findings of RANI *et al*. (2010) for fruit weight, acidity; MANNA and PAUL (2012) for fruit weight, pericarp thickness; KUMARI and SHARMA (2013) for pericarp thickness and titrable acidity. Days to flower initiation, ascorbic acid, dry matter, number of locules, plant height, fruit shape index, days to first harvest, total soluble solids and lycopene content had negative, direct, effects on total fruit yield, indicating that these characters are not effective paths to influence total fruit yield. The results agree with findings of KUMAR and DUDI (2011) for ascorbic acid, dry matter content, number of locules per fruit, lycopene content; RANI *et al*. (2010) for plant height and TSS; REDDY *et al*. (2013a) for days to flowering, days to first fruit harvesting, and KUMARI and SHARMA (2013) for fruit shape index.

Pericarp thickness had positive direct, and indirect, effects via marketable yield, number of locules, ascorbic acid, plant height, total soluble solids and days to flower initiation. Titrable acidity had positive direct, and indirect, effects via days to flower initiation, fruit weight, lycopene content and fruit shape index. Fruit weight had positive direct and indirect effects via marketable yield, dry matter, ascorbic acid, pericarp thickness, fruit shape index and days to first harvesting. Carotene content had positive, indirect, effects via marketable yield, fruit weight, ascorbic acid, number of locules and total soluble solids. Marketable yield had positive direct and indirect effects via days to flower initiation, carotene content, pericarp thickness, number of locules, dry matter, days to first harvesting, total soluble solids and fruit shape index.

Total soluble solids had a negative direct, and positive indirect, effect via ascorbic acid, titrable acidity, number of locules and fruit shape index. These results agree with KUMAR and DUDI (2011) for ascorbic acid. Lycopene content had negative direct, and positive, indirect effects via marketable yield, carotene content, ascorbic acid content, number of locules, pericarp thickness and days to first harvesting. Plant height had negative direct, and indirect, effects via pericarp thickness, dry matter, ascorbic acid content, number of locules, days to first harvesting, lycopene content, total soluble solids and fruit weight. There was a positive, indirect, effect via marketable yield, days to flower initiation, titrable acidity, fruit shape index and carotene content. MOHANTY (2000) reported negative direct effect of plant height on total fruit yield of tomato.

Generally genotypic diversity is considered as a criterion to measure genetic diversity in crop plants which often fails to convey information about genetic divergence. It is worthwhile to use the Mahalanobis statistics as described by RAO (1952). On the basis of the relative magnitude of D^2 value, the genotypes were grouped into 8 clusters, indicating the presence of a wide range of genetic diversity among the genotypes (Table 5). Cluster II had the majority of genotypes, followed by cluster V, and cluster VII. Clusters III, VIII, I, VI and IV had fewer genotypes. SHARMA and VERMA (2000) grouped divergent genotypes indicating no parallelism between genetic diversity and geographical divergence. This implied that genetic material from the same geographical region may provide substantial diversity. It also indicates that forces other than eco-geographical differentiation, i.e., natural and human selection pressure, could exert considerable influence on genetic divergence (GANESH *et al*., 2007).

Inter- and intra-cluster divergences exist (Table 6). Maximum inter-cluster distance occurred between clusters VI and VIII indicating the genotypes in group VI were the most divergent from those of group VIII, indicating greater diversity between genotypes belonging to these clusters and genotypes included in these clusters can be used as parents in hybridization (KUMAR *et al*., 2010). The minimum inter-cluster D^2 value was between clusters IV and VI indicating a close relationship between members of these clusters. The minimum intra-cluster distance D^2 value was zero within cluster V, VI and VIII, indicating a close relationship among members of same group; the maximum intra-cluster D^2 value was for cluster II followed by cluster VII, indicating considerable genetic divergence among genotypes of the cluster. Parents within a cluster can be used for hybridization (KUMAR *et al*., 2010).

Table 5. Clustering pattern of 54 genotypes of tomato on the basis of genetic divergence

Cluster	Genotype	Frequency
I	FLA 456-4, CLN 2679 F,CLN 2714 J	3
II	LBR 9, LBR 11, LBR 16, CLN 2413 R, CLN 2366 C-1, CLN 1314 G, CLN 1460 A, CLN 1462 A, CLN 1462 B, CLN 1464 A, EC 654789, CLN 2366 C, LBR 12	13
III	CA 4, CLN 2585 C, EC 654760, CLN 1621 L, CLN 2123 C, CLN 2123 D, CLN 2026 D, EC 15988	8
IV	LBR 17	1
V	CLN 2679 E,CLN 2366 A, CLN 3022- F_2-37-8-1,CLN 3010- F_2-76-9-13-0, CLN 3022- F_2-138-6-2-0, CLN 3022-F_2-138-6-7-0, CLN 3024- F_2-104-48-1-0, EC 11975, Punjab Chhuhara, Punjab Ratta, Punjab Upma	11
VI	Ty52, CLN 3022- F_2-154-11-11-0	2
VII	CLN 2714 G, CLN 2714 H, LBR 10, CLN 3008- F_2-132-17-10-0, LBR 19, EC 654768, CLN 2418 A, LBR 13, LBR 15, EC 531802	10
VIII	CA 2, CLN 2366 B, CLN 1464 B, CLN 3022- F_2-37-29-8-0, CLN 2777-F-18-9, CLN 5915-206 D4	6

Table 6. Average intra- (bold) and inter-cluster D^2 value.

Cluster	I	II	III	IV	V	VI	VII	VIII
I	**214.39**	1110.62	474.70	2499.69	2938.59	3231.97	1677.80	12396.55
II		**318.69**	725.57	579.02	823.05	964.42	4845.47	19721.75
III			**99.62**	1680.33	1731.17	2482.05	2802.48	15089.19
IV				**0.00**	294.26	191.02	7749.85	25456.34
V					**0.00**	652.03	8347.39	26263.41
VI						**0.00**	8978.97	27638.44
VII							**223.24**	5240.13
VIII								**0.00**

Cluster means for various characters varied (Table 7). The cluster means indicated considerable differences for plant height, fruit weight, days to first harvest, number of locules, ascorbic acid content, days to flower initiation, total fruit yield, marketable yield, pericarp thickness, fruit shape index, total soluble solids, dry matter, titrable acidity, lycopene content and carotene content. Clusters IV had maximum values for total soluble solids, lycopene content, and fruit weight, and a minimum value for days to first harvest. Cluster IV was the earliest in maturity. Cluster V had the highest values for pericarp thickness, marketable yield and total fruit yield.

Table 7. Cluster means for yield components and quality traits.

	Character														
Cluster	Plant height (cm)	Days to flower initiation	Days to first harvest	Marketable yield (kg/plant)	Total fruit yield (kg/plant)	Fruit weight (g)	Pericarp thickness (mm)	No. locules	Fruit shape index (cm)	Total soluble solid (°Brix)	Dry matter (%)	Ascorbic acid (mg/100 ml of juice)	Titrable acidity (g/100 ml of juice)	Lycopene Content (mg/100g of fresh	Carotene content (mg/100 g)
I	90.78	46.78	145.44	0.80	0.91	76.50	4.24	4.72	1.07	3.61	4.11	54.26	0.71	1.46	1.05
II	102.03	47.69	146.28	2.08	2.18	102.77	5.03	4.27	0.89	3.40	3.90	48.72	0.66	2.30	0.79
III	87.79	44.92	146.00	1.81	1.99	58.48	5.86	3.01	1.13	3.09	4.15	56.65	0.71	1.37	0.56
IV	94.33	61.67	141.00	2.00	2.05	236.89	5.30	3.19	0.83	4.47	3.07	17.15	0.38	3.54	0.82
V	95.88	45.49	146.91	2.15	2.32	66.44	5.95	3.19	1.16	3.51	3.84	45.67	0.61	2.67	1.06
VI	66.17	51.17	148.00	1.00	1.19	43.38	5.04	2.02	1.22	3.87	3.94	26.19	0.74	2.01	0.98
VII	83.43	48.00	150.67	1.59	1.66	91.18	5.23	4.70	0.92	3.84	3.46	62.78	0.77	1.02	0.51
VIII	78.28	55.67	149.28	1.37	1.46	59.35	5.89	2.53	1.04	3.64	4.23	37.73	0.53	2.53	1.12

Table 8. Contribution of individual characters towards divergence

Source	Times ranked 1st	Contribution %
Plant height (cm)	20	1.40
Days to flower initiation	1	0.07
Days to first harvest	2	0.14
Marketable yield (kg/plant)	175	12.23
Total yield (kg/plant)	14	0.98
Fruit weight (g)	1145	80.01
Pericarp thickness	1	0.07
No. locules	3	0.21
Fruit shape index	7	0.49
Total Soluble Solids (°Brix)	1	0.07
Dry matter (%)	1	0.07
Ascorbic acid (mg/100 ml of juice)	13	0.91
Titrable acidity (g/100 ml of juice)	3	0.21
Lycopene content (mg/100 g of fresh wt.)	45	3.14
Carotene content (mg/100 g of fresh wt.)	0	0.00

Cluster III had the lowest value for days to flower initiation. Cluster II had the greatest value for plant height. High carotene content and dry matter content were found in Cluster VIII. The minimum number of locules was in Cluster VI. High ascorbic acid and titrable acidity were reported in cluster VII. Depending upon breeding objective, potential lines to be selected from different clusters as parents in a hybridization program may be based on genetic distance (HAZRA *et al*., 2010). The percent contribution of characters for genetic divergence (Table 8) indicated fruit weight contributed the most toward genetic divergence followed by marketable yield, and lycopene content. MOHANTY and PRUSTI (2001), and REDDY *et al*. (2013b) reported these types of contribution for fruit weight to total divergence of tomato genotypes.

CONCLUSIONS

Fruit yield is a very important character and genotypes 'CLN 3024- F_2-104-48-1-0' and 'CLN 3022- F_2-138-6-7-0' were good for yield traits. It is expected that crosses involving widely divergent parents from clusters VI and VIII would result in greater heterotic effect and phenotypic stability and more transgressive segregants.

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GENETIČKA SRODNOST I DIVERZITET GENOTIPOVA PARADAJZA ZASNOVANI NA MORFOLOŠKIM MARKERIMA

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Izvod

Za povećanje produktivnosti paradajza (*Solanum lycopersicum* L.) neophodno je stvaranje superiornih hibrida, što delimično zavisi od varijabilnosti genetičkog materijala, odnosno agro-morfoloških i biohemijskih karakteristika. Istraživanje je sprovedeno na 51 genotipu paradajza i standardima cv. Punjab Upma, Punjab Chuhhara i Punjab Ratta, u cilju određivanja vrste povezanosti, path analize i genetičkog diverziteta i odabira genotipova i osobina za oplemenjivanje. Razlike u genotipovima za sve osobine ukazale su na visok stepen varijabilnosti. Visoko značajne, pozitivne korelacije, kao i visok direkan efekat na težinu ploda i tržišnu vrednost na ukupni prinos ploda, ukazujući da su te osobine značajne komponente za odabir visoko prinosnih genotipova paradajza. D^2 statistika je potvrdila najveću distance između klastera VI I VIII (27638.44), dok je maksimalna sličnost bila između klastera IV i VI (191.02). Ovo ukazuje na mogućnost popravke genotipova kroz hibridizaciju iz bilo kog para klastera, a zatim se selekcija može vršiti iz segregirajućih generacija.

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