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Estimating Combining Ability Effect of the Indian and Exotic Lines of Tomatoes by Partial Diallel Analysis

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A B S T R A C T

Eight nearly homozygous, horticulturally superior and optimally divergent lines of tomato having Indian and exotic adaptability were used for carrying out half diallel design to study General Combining Ability (GCA) and Specific Combining Ability (SCA) estimates for fruit weight, polar and equatorial diameter, locules fruit^{-1}, pericarp thickness and fruit firmness. The variances due to both GCA and SCA were significant, suggesting that both additive and non additive genetic variance were involved for genetic control of the character fruit polar and equatorial diameter, and locules number in F_1 and F_2 generations. However, the variance due to GCA was more pronounced for fruit weight, pericarp thickness and firmness as a result of additive gene action. Due to their high general combining ability effects, exotic parents Ec 490130 and Ec 177371 producing firm fruited small to medium sized tomato fruits having constant expression of GCA effects over the generationsregarded as best general combiners. The crosses GT 1 x Ec 490130 and Ec 490130 x Ec 398704 having high x high and high x low combinations, respectively in F_1. While in F_2, GT 1 x Ec 177371 and H 24 x Ec 490130 having high x high and high x low combining lines were considered as best crosses for greater fruit firmness. Therefore, heterosis breeding in F_1 and selection of desirable lines in F_2 generation is recommended for further improvements were suggested for future hybridization programmes.

Introduction

Tomato (*Solanum lycopersicon* L.) is a major horticultural crop with an estimated global production of over 162 million metric tons from an area of 4.83 million hectares (FAO, 2014). Tomato is being produced in most of the countries of the world and United States, China, Turkey, Italy and India are the major producers. There has been an increase of 60% in the world tomato production over the recent many years. In India, it is the second most important vegetable crop next only to potato. During 2012-2013, tomato was cultivated over an area of 888000 hectares with a production of 18228000 tones (Anon, 2014). The wide adaptation of tomato in different environments, methods of production and versatility in its uses is attributed to existing genetic variation in the genus *Solanum*. Due to its flowering behaviour, genetic variability of tomato can easily be exploited for the developing high yielding hybrids having desirable and specific characteristics.

Salad tomatoes must have a flavour, colour and texture that satisfy the consumer's preference. At the same time they must be suitable for post-harvest handling and marketing, even over large distances. Fruit firmness is an important quality character for marketing, transportation and domestic use. Consumer perception of the quality of tomato fruits for fresh consumption is determined by appearance, firmness and flavour Stevens (1986). Locules present in tomato fruit play an important role in governing its quality as it is primarily correlated with fruit size and number of fruits Bhutani and Kalloo (1991) and negatively associated with fruit firmness Thakur and Kohli (2005). Hence development of firm fruited tomato having a few locules and large size is the basic need for market quality.

Although many commercial cultivars have high agronomic performances, they perform poorly because of some genetic hindrances in diverse cross combinations. Thus crossing in a diallel fashion is the only specific and flourishing approach of measurement for the identification and selection of superior genetically recombined material. Combining ability is one of the most effective devices for selection of superior parents for hybridization and provides valuable information regarding crosses combinations to be exploited commercially also. Hence the current study was carried out to analyse some important tomato cultivars/genotypes to ascertain the relative performance regarding combining ability effects for fruit quality traits.

Materials and Methods

Materials

The experiment for the present investigation was carried out in randomized block design with three replications. Experiment was conducted at Junagadh Agricultural University (JAU), Junagadh. Geographically Junagadh is located at 21.5° N latitude and 70.5° E longitudes with an altitude of 60 m above the mean sea level. Eight tomato inbred lines *viz.*, P_1 (Gujarat Tomato 1), P_2 (Pusa Ruby), P_3 (H 24), P_4 (Ec 490190), P_5 (ArkaVikas), P_6 (Ec 177371), P_7 (IC 89976) and P_8 (Ec 398704) were crossed in half diallel fashion to get F_1 seeds (Table 1). All the F_1 seed was sown and at the time of pollination about 10 plants were selfed to get F_2 seeds. The parents, F_1 hybrids and F_2 population were field evaluated using randomized complete block design with three replications. Evaluation of 64 treatments (28 F_1s hybrids, 28 F_2s, 8 parents) was done at a spacing of 75 x 60 cm by following recommended olericultural practices of JAU, Junagadh obligatory to raise healthy crop. Standard cultural practices included pre planting application of farmyard manure at the rate of 20 t/ha, and 37.5 kg/ha each of N, P and K as basal dose. One month after planting 37.5 kg/ha N was top dressed. The irrigation was given as and when required.

The observations were recorded for fruit weight, equatorial and polar diameter, number of locules, pericarp thickness and firmness. Fruit firmness was judged as per the method reported by Nanadasana (2005) using Texture Analyser TA XT2i instrument, a microprocessor analysis system developed by Stable Micro Systems England. The Texture Analyser measures force, distance and time. It consists of two separate module *viz.,* the test bed and the console (keyboard). To obtain a great amount of analytical flexibility, the texture analyser was interfaced with an IBM PC with software called “Texture Expert” which facilitate to view the data in a graphical format, finding multiple peaks, areas and averages and saving of data on the disk. The results were read directly from the saved graphs in computer directly. The compression test was used to evaluate the force required to rupture the tomato fruits under quasi stable loading. The following TA XT2i setting was done for the compression test

- *Mode:* measures force in compression
- *Option:* return to start
- *Pretest speed:* 2 mm s^{-1}
- *Posttest speed:* 10 mm s^{-1}
- *Distance:* 15 to 20 mm
- *Trigger type:* Auto 20
- *Data acquisition rate:* 200 pps
- *Accessory:* 75 mm compression platen (P/75) using 20 kg load cell

For each test a single tomato fruit was placed centrally on blank plate secured on the heavy duty platform. The static compression test of the whole fruit was carried out at predetermined speed, forcing the flat platen kept on the fruit to apply pressure around the mid region to fruit *i. e.* with pedicel end at right angle to the direction of force.

Table 1 Source and some diagnostic features of homozygous parental lines in the 8 x 8 partial diallel analysis in tomato

Code No.	Parent	Source/Origin	Salient features
P_1	Gujarat Tomato 1 (GT 1)	Vegetable Research Station, J. A. U., Junagadh (Gujarat)	Indeterminate plant habit, popular in Gujarat high yielding, fruits are red round, pulpy consistency and have green shoulder.
P_2	Pusa Ruby	Indian Agricultural Research Institute, New Delhi	Popular variety produced by hybridisation of Sioux x Improved Meeruti. Plants are early, indeterminate, spreading, hardy. Uniform light red, medium sized and have flattish round fruits.
P_3	H 24	Haryana Agricultural University, Hisar	Fruits are red, round, medium sized and pulpy but susceptible to cracking. Plants tolerant to TLCV.
P_4	Ec 490130	National Bureau of Plant Genetic Resources, New Delhi	Plants are determinate with potato leaf shape. Fruits are orange red in colour, medium in size, roundish, firm, have few locules and thick pericarp.
P_5	Arka Vikas	Indian Institute of Horticultural Research, Bangalore	Indeterminate type does well in stress condition. Fruits are medium in size, flat round, uniform red colour and have high TSS.
P_6	Ec 163599	National Bureau of Plant Genetic Resources, Hyderabad	Indeterminate plant habit. Fruits are flattish round, small to medium in size having deep red colour and are pulpy.
P_7	Ec 177371	National Bureau of Plant Genetic Resources, New Delhi	Plants are early, spreading with good branching habit. Produces 4 to 5 fruits in cluster. Fruits small oblong shaped, orange red Coloured and pulpy.
P_8	Ec 398704	National Bureau of Plant Genetic Resources, New Delhi	Indeterminate and spreading plants. Fruits are flattish round, deep red coloured, slightly lobed, pulpy and are small to medium in size.

Once a trigger force of 20 g had been achieved the compression platen proceeded to move down on to the tomato fruit at constant loading velocity up to predetermined distance at which fruit gets rupture. At the same time, the force applied and corresponding deformations was observed from computer and results were saved on the disk. In this way this test was conducted for five tomato fruit immediately after harvest and average values are reported. The average values for fruit firmness (kg/cm) were calculated using following formula. Fruit firmness (kg/cm) = Fruit first rupture force (kg)/Deformation (cm).

Statistical Analysis

The observations were recorded on sample fruits randomly selected from five plants of each parent, F_1 and check variety and 30 plants of F_2 genotypes were compiled and averaged values of the replicated data were used for statistical analysis. The mean of each replication were tested for significance by the method suggested by Panse and Sukhatme (1987).

Combining Ability Analysis

Combining ability analysis not only helps in identification and early assessment of breeding potential of parental lines to be included in crossing programme but also provides specific promising cross combinations to exploit heterosis or mop up the favourable fixable genes. Mean of 28 of each F_1 and F_2 progenies were arranged in a diallel table and data obtained were subjected to combining ability analysis by using model I, method 2 as described by Griffing (1956). It included parents and one set of F_1s without reciprocals. In this method, the experimental material is considered as a population about which the inferences are to be drawn and combining ability effects of the parents could be compared when parents themselves were used as testers to identify good combiners. In model I, it was assumed that the variety and block (replication) effects were constant but error was variable and was normally and independently distributed with zero mean and (σ^2) variance.

Results

A diallel analysis of 28 F_1s and F_2s developed by crossing eight parents excluding reciprocals was carried out for tomato fruit characters. Analysis of variance revealed (Table 2) highly significant differences among the genotypes, parents, and hybrids for all the characters indicating the presence of significant variation among the genotypes as well as crosses studied.

Combining Ability Analysis

Nature of gene action

The variations existing in the experimental material studied were partitioned into components attributable to parents, F_1, F_2 and error sources. Further, using appropriate expectation of the observed mean squares, the component of variance attributed to parents were used as a measure of general combining ability (σ^2 g), while, the variances observed due to different cross interaction were used as a measure of specific combining ability (σ^2 s). Further ratio between these two estimates (σ^2 g and σ^2 s) was worked out to find out nature of gene action involved in governance of the individual character (Table 3)

Mean squares of general and specific combining ability for all studied traits are presented in Table 3. The results showed that mean squares of general combining ability (GCA) and specific combining ability (SCA) were highly significant for all studied traits. The variances due to both GCA and SCA were significant, suggesting that both additive and non additive genetic variance were involved for genetic control of the character fruit polar and equatorial diameter, and locules number in F_1 and F_2 generations. However, the variance due to GCA was more pronounced for fruit weight, pericarp thickness and firmness as a result of additive gene action. Meanwhile, variance due to SCA as an indicator of non additive gene action, was greater for fruit polar diameter. The predictivity ratio further confirmed importance of additive genetic variance in the governance of these traits in both F_1 and F_2 generations.

GCA effects (gi)

The GCA effects of the parents used in the study for fruit characters are given in Table 4. After the assessment of overall picture of GCA effects, it appeared that the parents differ in their GCA. Among the lines, the highest significant and positive GCA effects had shown by Ec 490190 for maximum number of characters namely fruit weight, polar and equatorial diameter, Number of locules/fruit, pericarp thickness and fruit firmnessover the generations. Next to Ec 490190, significantly positive GCA effects for fruit weight was shown by the parent H 24 was the better in F_1 generation indicating its feasibility of exploitation on commercial scale. Parent Ec 163599 had best performance for locules per fruit and fruit firmness, polar diameter and pericarp thickness thus indicating exploitation by heterosis breeding. Analysis of variance as well as predictivity ratio revealed additive genetic inheritance of mean fruit weight in both sets.

Table 2 Analysis of variance for combining ability of characters of tomato

Source	DF[1]	FW[2]	FPD[3]	FED[4]	NLF[5]	FPT[6]	FF[7]
Replications	2	6228.44**	1.78**	2.61**	1.15**	0.032**	0.98**
Genotypes	64	357.82**	0.86**	1.76**	2.61**	0.030**	1.03**
Parents	7	372.28**	0.97**	1.86**	3.24**	0.018**	0.42**
F_1s	27	205.37**	0.095**	2.02**	2.01**	0.019**	1.12**
F_2s	27	350.76**	1.54**	0.88**	3.20**	0.040**	1.01**
P Vs F_1	1	831.91**	5.40**	4.14**	0.096	0.130**	0.71**
P Vs F_2	1	315.55**	0.25**	0.83**	0.093	0.180**	0.023*
Error	128	7.69	0.013	0.034	0.044	0.002	0.006

[1]DF: Degrees of freedom; [2]FW: Fruit weight (g); [3]FPD: Fruit polar diameter (cm); [4]FED: Fruit equatorial diameter (cm); [5]NLF: Number of locules fruit-1; [6]FPT: Fruit pericarp thickness (cm); [7]FF: Fruit firmness (kg/cm); * Significant at 5 % level** Significant at 1 % level

Table 3 Analysis of variance for combining ability for fruit characters in tomato

Effect	Generation	DF[1]	FW[2]	FPD[3]	FED[4]	NLF[5]	FPT[6]	FF[7]
GCA	F_1	7	85.093**	0.147**	1.379**	2.655**	0.015**	0.598**
	F_2	7	181.03**	0.147**	1.379**	2.619**	0.008**	0.528**
SCA	F_1	27	79.614**	0.082**	0.524**	0.161**	0.006**	0.285**
	F_2	27	88.093**	0.082**	0.524**	0.653**	0.015**	0.213**
Error	F_1	70	3.934	0.003	0.016	0.018	0.001	0.001
	F_2	70	3.988	0.003	0.016	0.004	0.001	0.003
6^2 GCA	F_1		81.159	0.144	1.363	2.637	0.014	0.597
	F_2		177.042	0.144	1.363	2.615	0.007	0.525
6^2 SCA	F_1		75.68	0.079	0.508	0.143	0.005	0.284
	F_2		84.105	0.079	0.508	0.649	0.014	0.21
(Predictivity ratio)	F_1		0.517	0.646	0.728	0.949	0.737	0.678
	F_2		0.678	0.646	0.728	0.801	0.333	0.714

[1]DF: Degrees of freedom; [2]FW: Fruit weight (g); [3]FPD: Fruit polar diameter (cm); [4]FED: Fruit equatorial diameter (cm); [5]NLF: Number of locules/fruit; [6]FPT: Fruit pericarp thickness (cm); [7]FF: Fruit firmness (kg/cm); *, ** Significant at P <0.05 and 0.01, respectively

Table 4 Estimates of general combining (GCA) ability effects in 8 parents.

P[1]	FW[2]		FPD[3]		FED[4]		NLF[5]		FPT[6]		FF[7]	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
P_1	2.272**	-0.51	0.098**	-0.318**	0.05	0.072**	0.158**	0.300**	-0.021*	-0.026**	0.240**	0.114**
P_2	2.973**	7.234**	0.070**	0.128**	0.580**	0.482**	0.971**	0.950**	0.01	0.003**	-0.455**	-0.236**
P_3	0.14	-2.226**	-0.051**	-0.02	0.101**	0.051**	0.03	0.01	-0.041**	-0.005**	0.038**	0.037*
P_4	3.434**	5.395**	0.160**	0.343**	-0.113**	0.199**	-0.815**	-0.780**	0.072**	0.047**	0.336**	0.313**
P_5	0.48	-1.887**	0.01	0.097**	0.446**	0.106**	-0.01	-0.127**	0.033**	0.037**	-0.137**	-0.160**
P_6	-2.284**	0.48	-0.03	-0.061**	-0.217**	-0.212**	-0.160**	0.222**	0	-0.015**	0.031**	-0.151**
P_7	-2.135**	-4.599**	-0.01	-0.232**	-0.447**	-0.418**	-0.391**	-0.246**	-0.038**	-0.028**	0.068**	0.315**
P_8	-4.874**	-3.889**	-0.243**	0.065**	-0.398**	-0.279**	0.216**	-0.326**	-0.022*	-0.013**	-0.121**	-0.233**
Gi	1.1701	1.1782	0.0325	0.0244	0.0737	0.0098	0.0799	0.0368	0.0195	0.002	0.0183	0.0338

[1]P: Parents; [2]FW: Fruit weight (g); [3]FPD: Fruit polar diameter (cm); [4]FED: Fruit equatorial diameter (cm); [5]NLF: Number of locules/fruit; [6]FPT: Fruit pericarp thickness (cm); [7]FF: Fruit firmness (kg/cm); P_1: GT 1; P_2: Pusa Ruby; P_3: H 24; P_4: Ec 490190; P_5: ArkaVikas; P_6: Ec 163599; P_7: Ec 177371; P_8: Ec 398704; Gi: Gi: GCA effect of parent; *, ** Significant at P <0.05 and 0.01, respectively

SCA effects (Sij)

Specific combining ability effects represents dominance and epistatic components of genetic variation which are not fixable but the crosses with high SCA effects involving good general combiner parents can be exploited in future heterosis breeding program. The estimates of SCA effects of F_1 and F_2 for various characters studied are presented in Table 5.

For fruit weight as many as 18 and 22 crosses recorded significant SCA effects in F_1 and F_2 generations, respectively (Table 5).

In F_1 highest and lowest SCA effects were observed in cross P_4 x P_7 (22.195) and P_1 x P_4 (-13.819), respectively. However, in F_2 the highest SCA effect were recorded by P_4 x P_8 (1.576) and the lowest by P_2 x P_4 (-1.199) cross. Four and three crosses for both larger and smaller fruit weight recorded constant performance over the generations. Correspondingly P_3 x P_8, P_1 x P_2 and P_2 x P_4 for larger fruits, had significantly positive SCA effects. While for smaller fruits, P_1 x P_4, P_2 x P_8 and P_3 x P_4 recorded stable negative SCA estimates.

The SCA estimates for fruit polar diameter ranged from 0.537 (P_1 x P_7) to P_3 x P_4 (-0.361) and 1.079 (P_4 x P_8) to -0.751 (P_1 x P_5) in F_1 and F_2 generations, respectively. As in the case of fruit weight, no correspondence was observed for SCA effects among intra generations. However, the cross P_1 x P_7 involving high x low combining lines was considered as best cross in F_1 generation.

Equatorial diameter of fruit is a character related with size of the fruit and the SCA estimate was significant for 15 crosses in F_1 and 27 crosses in F_2. The cross P_1 x P_7 in F_1 had the highest maximum (0.537) positive SCA effect followed by P_3 x P_8 (0.465), whereas, P_4 x P_8 (1.079) and P_1 x P_5 (-0.751) crosses, had the significant highest positive and negative SCA effects, respectively. The crosses P_4 x P_8, P_3 x P_7 and P_2 x P_6 displayed highest positive significant SCA effects while the P_1 x P_5 had least significant SCA effects in both generations.

Perusal of two sets of data, it was revealed that 14 and 12 crosses had significant SCA effects in F_1 and F_2 generation, respectively. In both F_1 and F_2 generations all the significant crosses had negative effects. However in both the generations, the cross P_4 x P_7 registered significantly negative stable SCA estimates (-0.312 and -0.158) hence, it was considered as best specific cross.

Estimates of SCA effects for pericarp thickness revealed that 12 crosses in F_1 had significant SCA estimates. Whereas, in F_2 22 crosses had significant estimates, corresponding positive SCA effects were noticed in nine and ten crosses. Among significant positive stable performing crosses, the cross P_1 x P_6 (0.111 in F_1 and 0.347 in F_2) recorded significantly superior SCA effects over the generations hence, were considered as the best specific cross which followed by P_3 x P_6 (0.068 in F_1 and 0.333 in F_2) and P_2 x P_3 (0.061 in F_1 and 0.274 in F_2) crosses.

Whole fruit firmness is an important quality trait that conditions the post harvest life of the produce. On the basis of two generations data it was observed that eight crosses exhibited stable performance. In that P_1 x P_8 cross (0.534 in F_1 and 0.505 in F_2) had higher GCA estimate in desired direction over the generations. Whereas, the cross P_2 x P_8 (-0.921 in F_1 and -0.479 in F_2) had constantly significant negative SCA effects in both generations.

Table 5 Estimates of specific combining ability (SCA) effects of 28 F_1s and F_2s in tomato

C[1]	FW[2]		FPD[3]		FED[4]		NLF[5]		FPT[6]		FF[7]	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_1	F_1	F_2	F_1	F_2
P_1xP_2	5.432**	0.282**	0.061	-0.608**	0.152	-0.026	-0.1	-0.078	-0.062*	-0.099	-0.236**	-0.099
P_1xP_3	2.909	-0.438**	0.071	0.143**	-0.492**	0.815**	0.927**	-0.087	-0.018	-0.715**	0.038	-0.715**
P_1xP_4	-13.81**	-0.849**	-0.029	-0.345**	0.601**	-0.06	0.093	-0.002	0.046	-0.252**	0.813**	-0.252**
P_1xP_5	-3.905*	-0.373**	0.01	-0.751**	0.186	-0.222**	0.037	0.028	0.051	-0.369**	-0.150**	-0.369**
$P_{1x}P_6$	3.229	-0.066	-0.084	0.367**	-0.041	0.761**	-0.562**	0.200**	0.111**	0.347**	0.165**	0.347**
P_1xP_7	-0.05	-0.357**	0.537**	-0.338**	-0.615**	-0.274**	0.208	0.012	-0.024	1.220**	0.358**	1.220**
P_1xP_8	10.176**	0.179**	-0.08	0.084**	-0.254*	-0.354**	-0.346**	-0.022	-0.054	0.505**	0.534**	0.505**
P_2xP_3	-3.442	0.036	-0.121**	-0.357**	-0.442**	-0.172**	-0.056	0.123*	0.061*	0.274**	0.194**	0.274**
P_2xP_4	6.093**	-1.199**	-0.158**	0.048**	0.122	-0.740**	-0.087	-0.152**	-0.055	0.391**	-0.388**	0.391**
P_2xP_5	1.821	0.001	0.091	-0.238**	-0.154	-0.372**	0.317**	0.099	0.027	0.181**	0.195**	0.181**
P_2xP_6	-1.993	0.558**	0.134**	0.260**	0.816**	2.455**	0.845**	0.104	0.124**	-0.134**	0.574**	-0.134**
P_2xP_7	-4.815**	0.450**	-0.005	0.082**	0.856**	-0.754**	-0.261*	0.106*	0.058*	0.093	0.307**	0.093
P_2xP_8	-11.45**	-0.267**	0.075	-0.257**	-0.947**	-0.504**	-0.505**	-0.061	0.008	-0.479*	-0.921**	-0.479**
P_3xP_4	-3.25	-0.579**	-0.361**	-0.454**	-0.803**	-0.275**	-0.646**	0.049	-0.111**	0.775**	-0.607**	0.775**
P_3xP_5	-10.49**	-0.149**	-0.175**	-0.241**	-0.731**	-0.097	-0.532**	-0.014	-0.033	-0.039	-0.768**	-0.039
P_3xP_6	8.231**	-0.562**	0.064	-0.093**	0.535**	-0.777**	0.142	-0.052	0.068*	0.333**	0.511**	0.333**
P_3xP_7	10.882**	-0.087*	0.185**	0.633**	1.405**	0.691**	-0.298*	0.08	0.029	-0.650**	0.204**	-0.650**
P_3xP_8	6.718**	1.576**	0.465**	-0.126**	1.316**	-1.063**	-0.145	0.139**	0.076*	-0.469**	0.320**	-0.469**
P_4xP_5	-6.550**	1.290**	-0.059	0.675**	0.412**	-0.142*	0.037	0.154**	0.028	0.142**	0.344**	0.142**
P_4xP_6	5.190**	0.314**	-0.153**	0.459**	0.435**	1.008**	0.275*	-0.094	-0.015	-0.363**	-0.157**	-0.363**
P_4xP_7	22.195**	-0.838**	-0.325**	-0.739**	-0.225*	0.303**	-0.312*	-0.158**	0.126**	-0.069	-0.338**	-0.069
P_4xP_8	-3.34	1.242**	0.181**	1.079**	0.016	-0.447**	0.328**	0.268**	0.123**	-0.242**	1.182**	-0.242**
P_5xP_6	-0.093	-0.377**	-0.094	-0.620**	-0.113	-0.144*	-0.115	-0.140**	-0.036	-0.357**	0.416**	-0.357**
P_5xP_7	9.145**	0.212**	0.054	0.588**	0.736**	0.494**	0.636**	0.139**	0.045	-0.266**	-0.011	-0.266**
P_5xP_8	9.831**	-0.502**	0.380**	-0.030*	1.491**	0.074	-0.121	-0.075	0.072*	-0.109*	-0.375**	-0.109**
P_6xP_7	4.092*	-0.014	0.186**	-0.004	-0.451**	-0.196**	0.11	0.154**	0.019	0.452**	0.120**	0.452**
P_6xP_8	1.508	-0.048	0.316**	-0.312**	-0.06	-1.116**	-0.054	-0.023	-0.071*	-0.097	-0.337**	-0.097
P_7xP_8	-5.584**	0.094	0.154**	-0.307**	-0.823**	0.202	-0.017	-0.021	-0.007	-0.293**	-0.761**	-0.293**
Range	-13.81	-1.19	-0.361	-0.751	-0.823	-1.116	-0.646	-0.158	-0.111	-0.715	-0.921	-0.715
	22.195	1.576	0.537	1.079	1.491	1.008	0.927	0.268	0.126	1.22	1.182	1.22
SE Sij	2.173	0.045	0.06	0.018	0.137	0.068	0.148	0.004	0.036	0.063	0.028	0.052
CDSij5%	4.333	0.09	0.098	0.029	0.221	0.111	0.241	0.105	0.058	0.101	0.055	0.102
CDSij1%	2.661	0.055	0.129	0.038	0.343	0.147	0.317	0.139	0.077	0.134	0.072	0.134

[1]C: Crosses; [2]FW: Fruit weight (g); [3]FPD: Fruit polar diameter (cm); [4]FED: Fruit equatorial diameter (cm); [5]NLF: Number of locules/fruit; [6]FPT: Fruit pericarp thickness (cm); [7]FF: Fruit firmness (kg/cm); P_1 - GT 1; P_2 - Pusa Ruby; P_3 - H 24; P_4 - Ec 490190; P_5 – ArkaVikas; P_6 - Ec 163599; P_7 - Ec 177371; P_8 - Ec 398704; *,** significant at 5 % and 1 % level, respectively

Table 6 Top three parents identified based on *per se* performance and GCA effects

C[1]	Best parent *per se* performance	Best parents for gca		Common parent on *per se* performance and GCA effects in both F_1 and F_2 generations
		F_1	F_2	
FW[2]	P_2 (53.99)	P_4 (3.434)	P_2 (7.234)	P_2
	P_4 (47.47)	P_2 (2.973)	P_4 (5.395)	P_4
	P_1 (46.42)	P_1 (2.272)	P_6 (0.480)	
FPD[3]	P_4 (4.18)	P_4 (0.160)	P_4 (0.343)	P_4
	P_2 (3.51)	P_1 (0.098)	P_2 (0.128)	P_2
	P_1 (3.36)	P_2 (0.070)	P_5 (0.097)	
FED[4]	P_2 (5.31)	P_2 (0.580)	P_2 (0.482)	P_2
	P_1 (4.68)	P_5 (0.446)	P_4 (0.199)	
	P_1 (4.33)	P_3 (0.101)	P_6 (0.106)	
NLF[5]	P_4 (2.17)	P_4 (-0.815)	P_4 (-0.780)	P_4
	P_7 (2.83)	P_7 (-0.391)	P_8 (-0.326)	P_7
	P_6 (3.01)	P_6 (-0.160)	P_7 (-0.246)	
FPT[6]	P_4 (0.50)	P_4 (0.072)	P_4 (0.047)	P_4
	P_5 (0.42)	P_5 (0.033)	P_5 (0.037)	P_5
	P_2 (0.38)	P_2 (0.010)	P_2 (0.003)	P_2
FF[7]	P_4 (3.05)	P_4 (0.336)	P_7 (0.315)	P_4
	P_7 (3.00)	P_1 (0.240)	P_4 (0.313)	P_7
	P_3 (2.94)	P_7 (0.068)	P_1 (0.114)	
	P_2 (1.09)	P_3 (3.111)	P_1 (4.033)	P_2
	P_5 (0.981)	P_1 (1.411)	P_5 (0.460)	

[1]C: Character; [2]FW: Fruit weight (g); [3]FPD: Fruit polar diameter (cm); [4]FED: Fruit equatorial diameter (cm); [5]NLF: Number of locules/fruit; [6]FPT: Fruit pericarp thickness (cm); [7]FF: Fruit firmness (kg/cm); P_1 - GT 1; P_2 - Pusa Ruby ; P_3 - H 24; P_4 - Ec 490190; P_5 – ArkaVikas; P_6 - Ec 163599; P_7 - Ec 177371; P_8 - Ec 398704

Discussion

The rapidly increasing vegetarian population of the world necessitates studying heterotic effects in vegetable crops for increasing vegetable yield potential. One of the means for the improvement of the yields and other characteristics in vegetable crops could be the use of F_1 hybrids. Through the genetic breeding, using the hybridization technique, plants of different vegetable crops have been obtained with a better adaptation to certain environments, more productive, resistant or tolerant to some specific insects or diseases, in general, plants with desirable agronomic characters, in particular. This could be achieved only by exploring maximum genetic potential from available germplasm of vegetable crops.

While studying the nature of gene action governing six traits, it has been observed that overwhelming additive gene action is responsible for the control of all the traits studied except fruit polar diameter, fruit equatorial diameter and locules per fruit for which preponderance of both additive and non additive gene actions was evident. The response of additive gene action for the conditioning of fruit weight by Conti (1974), Singh and Mital (1978) and Peter and Rai (1980); fruit equatorial diameter by Singh and Mital (1978), Peter and Rai (1980) and Rai et al. (1997); locules per fruit by Sidhu et al. (1981), Moya et al. (1986), Bhutani and Kalloo (1991) and Dhaliwal et al. (2000); fruit pericarp thickness by Raijadhav and Kale (1987) and Rai et al. (1997) and fruit firmness by Roopa et al. (2001), Rai et al. (2003) and Thakur and Kohli (2005) have been reported irrespective of the parental materials used, methods followed and environments in which experiments conducted. The successful breeding methods will be those that accumulate the genes to form superior gene constellations interacting in a favorable manner. These findings suggested heterosis breeding as the best possible option for improving the above traits of tomato.The response of non additive gene action in inheritance over the generations for the conditioning of fruit polar diameter was earlier reported by Singh and Mital (1978).

Parents P_4 (Ec 490130) and P_7 (Ec 177371) producing firm fruited small to medium sized tomato fruits had constant expression of GCA effects over the generations (Table 6). Hence, both exotic lines were regarded as best general combiners in the present study. However, no perfect correspondence between these high combiners in both generations was found with that of their respective combinations for SCA effects. Hence, P_1 x P_4 and P_4 x P_8 crosses having high x high and high x low combinations, respectively in F_1 only. While in F_2, P_1 x P_7 and P_3 x P_4 having high x high and high x low combining lines were considered as best crosses for greater fruit firmness. Therefore, heterosis breeding in F_1 and selection of desirable lines in F_2 generation is recommended for further improvement of this trait. Joshi et al. (2005) also reported best specific cross having other than best combining parents.

Conclusion

The concept of combining ability is a major landmark in understanding the genetic architecture of populations and in planning breeding programmes. It helps in choosing the parents for hybridization for isolating desirable recombinants in advanced generations or for using in heterosis breeding. The hybrid breeding programme in several crops is primarily based on the concept of specific combining ability.

From the data presented in this study, it could be concluded that the cross combination P_1 x P_4 and P_4 x P_8 showed desirable SCA effects in F_1 and the crosses P_1 x P_7 and P_3 x P_4 in F_2 for fresh fruit firmness. Therefore these promising crosses could be used for developing tomato hybrids for distant markets.

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