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Research article

PARENT OFFSPRING RELATIONS OF NUTRITIONAL QUALITY TRAITS IN 8 X 8PARTIAL DIALLEL CROSS OF FRESH TOMATOES

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ABSTRACT: Combining abilities for nutritional quality content were examined in tomato to understand the inheritance pattern of total soluble solids, titrable acidity, carbohydrates, proteins, carotenoids, ascorbic acid, potassium, lycopene and fruit yield plant^{-1}. This experiment comprising a total of 64 treatments (28 F_1+28 F_2+ 8 parents) was evaluated in RBD. The results indicated that most of the traits were governed by additive gene action however non additive gene actionwas also important. The parent Pusa Ruby was found to be good general combiners for yield and nutritional traits and hence could be utilized in multiple breeding programs in future. The cross Pusa Ruby x Arka Vikas was desirable for fruit yield as well as nutritional characters since it inherited all nutritional traits except TSS content in F_1generation and carotene content in F_2 generation in desired direction.

Key words: Diallel analysis, combining ability, *Solanum lycopersicon,* generations, nutritional quality

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is being produced in most of the countries of the world with an estimated global production of over 162 million metric tons from an area of 4.83 million hectares (FAO 2014). The United States, China, Turkey, Italy and India are the major producerswhere tomato is consumed as salad, cooked or processed into several preferred by products like ketchup, juice, puree, sauce and whole canned fruit. It isthe second most important vegetable crop next only to potato in India. During 2012-13, tomato was cultivated over an area of 8.88 lakh hectares with a production of 182.28 lakh tones (Anon 2014). “Hidden hunger” or micronutrient and vitamin deficiencies is a pernicious problem around the world that is caused by a lack of vitamins and minerals such as vitamin A, iodine and iron in the human diet. It affects the health of between 2 and 3.5 billion people in the developing world and increases the risk of illness or death from infectious diseases and children do not develop to their full physical or mental potential (Dias 2012 a).Tomato is a rich source of antioxidants (mainly lycopene and β-carotene), Vitamin A, Vitamin C and minerals like Ca, P and Fe in diet (Saleem *et al.* 2013).It is a rich source of lycopene antioxidant that reduces the risk of prostate cancer (Hossain *et al.* 2004).

Regular consumption of a vegetable rich diet has immense positive effects on health since phytonutriceuticals of vegetables can protect the human body from several types of chronic diseases. Various phytonutriceuticals with antioxidant properties may work directly by quenching free radicals or indirectly by participating in cell signaling pathways sensitive to redox balance. Nutrients such as potassium contribute to blood pressure regulation.Research on the health benefits of vegetables, from a horticultural and breeding perspective, needs to focus on key areas in the near future to continue the evaluation of phytonutriceuticals content among older versus newer major cultivars (Dias 2012 b). Nutritional quality as understood by the consumers and available at a moderate price may encourage enhanced consumption, thereby conferring an important marketing incentive to vegetable breeding.Successful breeders need to anticipate these changes and develop vegetable breeding strategy that is dependent on market trends by developing new cultivars which will be released to the growers when their demand increases.However within cultivated tomato, genetic variation is very low thus, there has long been an interest in searching for genes in exotic and primitive germplasm.

Landraces are heterogeneous, genetically dynamic populations that have evolved under low inputs of soil and agrochemicals and have been subjected to selection pressures for hardiness and local adaptability, rather than for productivity (Frankel *et al.* 1995). Also these landraces have shown large and significant variation in flavour volatiles (Ruiz *et al.* 2005) and nutritional constituents (Andreakis *et al.* 2004).

Since vegetables are rich in vitamins, minerals and other micronutrients, and therefore vital for health, breeding objectives should include improving their nutritional value. Historically vegetable breeders have applied selection pressure to traits related to agronomic performance, particularly yield and quality, because these are the traits important to the producer. Rarely have growers been paid for nutritional factors, so there have not been economic incentives to pay much attention to these traits. However, consumers are becoming more aware of these traits (Dias 2012 c). By the phenomenon of heterosis in 1907, many studies on the hybrid approaches, heterosis and combining ability estimates in tomatoes were conducted. But this hybrid seed technology prevents growers from saving seed from their harvest, thus forcing them to return to the commercial seed market every year. If the farmers wants to save and produce own seeds, segregation and reduction in heterozygosity adversely affect the quantity and quality of the produce in F_2 generation. Hence residual heterosis, if manifested in the F_2 generation would offer further scope as the grower need not get the highly priced F_1 seeds every year. Manifestation of hybrid vigour in F_1 and its retention in F_2 generation of tomato has been earlier reported by Choudhary *et al.* (1965) and Kanthaswamy and Balakrishnan (1989) and Dagade *et al*. (2015 a and b).Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits. In this context the present investigation was undertaken to generate information about combining ability which would help to assess the prepotency of parents in hybrid combinations in F_1 and F_2 generations.

MATERIALS AND METHODS

Materials

Present investigations were conducted at Junagadh Agricultural University, Junagadh (Gujarat). Geographically Junagadh is located at 21.5^0 N latitude and 70.5^0 E longitudes with an altitude of 60 m above the mean sea level. The experimental material consisted of eight genetically diverse tomato inbred lines *viz.,* P_1 (Gujarat Tomato 1, GT 1), P_2 (Pusa Ruby), P_3 (H 24), P_4 (Ec 490190), P_5 (Arka Vikas), P_6 (Ec 163599), P_7 (Ec 177371) and P_8 (Ec 398704) which were crossed in half diallel fashion to get F_1 seeds (Table 1 and Plate 1). All the F_1 seed was sown and at the time of pollination 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. All the 64 genotypes (8 parents, 28 F_1 hybrids and 28 F_2) were evaluated; the seedlings were transplanted in a randomized block design with three replications at the spacing of 75 cm x 60 cm. Recommended cultural practices and plant protection measures were followed. The observations were recorded for eight fruit nutritional quality parameters *viz.,* total soluble solids (^{0}Brix), total titrable acidity (%), carbohydrates (mg100 g^{-1}), proteins (%), carotenoids (mg 100 g^{-1}), ascorbic acid (mg 100 g^{-1}), potassium (g 100 g^{-1}), lycopene (mg 100 g^{-1}) and fruit yield plant^{-1} (Kg).

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).

Biochemical analysis

Analytical method suggested by Ranganna (1977) was followed for the estimation of total carbohydrates, protein, ascorbic acid and potassium content. The *Beta* carotene content was estimated as per Saini *et al.* (2001) and lycopene as per procedure of Adsule and Ambadan (1979).

Combing Ability Analysis

Combing 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 AND DISCUSSION

Significance of analysis of variance

Mean squares due to genotypes were highly significant for all the characters studied indicating existence of considerable amount of variability among the genotypes (Table 2). The block effects were highly significant for all the characters except for protein content and Vitamin A content indicating homogenity of the experimental block for these traits and heterogeneity for rest of the characters.Further a partitioning of analysis of variance revealed that parents, F_1 and F_2 differed significantly among themselves for all the characters except protein content for which genotypic differences between parents were non significant. The parents' vs F_1 comparison was highly significant for all the traits. Whereas, parents vs F_2 portion was highly significant for all the traits except protein content.

Significance of analysis of variance for combining ability

Analysis of variance for general and specific combining ability was carried out to ascertain the nature and magnitude of gene actions involved in the inheritance of different traits. The mean squares due to both gca (parents) and sca (F_1 and F_2) were significant for all the characters under study, indicating that both parents and their 28 cross combinations in F_1 as well as in F_2 generations significantly differed for their combining ability effects. The estimates of gca effects of parents and sca effects of F_1 and F_2 for characters studied are presented in Table 4 and 5, respectively.

The estimates of variance due to general combining ability were larger in comparison to variance due to specific combining ability for all the 21 characters studied in both generations, indicating greater influence of general in comparison to non additive gene action in the control of traits.The ratio estimates were greater than 0.50 for all the character under present except for the character fruit yield kg plant^{-1} in both generations indicating importance of additive genetic variance in the inheritance. While, for ascorbic acid and carbohydrate content, importance non additive variance was revealed due to less than 0.50 estimates of predictivity ratio in F_2 generation.Tomato fruit nutritional quality charactersare discussed in following pages

Total soluble solids

Mean squares due to both gca and sca were significant indicating involvement of both additive and non additive gene action (Shende *et al.* 2012). However, greater proportion 6^2gca than 6^2 sca and greater than 0.50 estimates of predictivity ratio confirmed additive inheritance of TSS content in the present study; which is in conformity with earlier studies (Dhaliwal *et al*. 1999, Thakur and Joshi 2000 and Kumar *et al*.2013). In general, all the parents except P_3 in F_1 and P_5 in F_2 had highly significant gca effects in positive or negative direction. Two parents *viz.,* P_2 (0.357 in F_1 and 0.326 in F_2) and P6 (0.065 in F_1 and 0.163 in F_2) had consistently stable positive gca effects desired for higher TSS. Whereas, P_8 had consistently significant negative gca estimates desired for lower TSS content.

Perusal of gca effects over both generations revealed constantly higher combining nature of parent P_2 although its rank magnitude differed among the estimates. This parent contributed significantly for TSS content when crossed with P_6 in both generations constantly. In addition to P_2 x P_6, cross P_1 x P_7 also had high sca effects. Both these crosses involved high x high combining lines. However, among these two crosses, P_2 x P_6 is favoured since it expressed significant increase in TSS content in F_2 generation.

Fruit acidity

Titratable acidity, pH, fruit firmness are important fruit quality characteristics of tomato. Organic acids give the fruits sourness, and affect flavour by acting on the perception of sweetness.Acidity influences storability of processed tomato. Lower pH reduces the risk of pathogen growth in tomato products, such as *Bacillus coagulans*, which is found to be completely inhibited by a pH below 4.1. For this trait preponderance of additive gene action was confirmed from analysis of variance, greater magnitude of 6^2gca and predictivity ratio. Trinklen and Lambeth (1975), Singh *et al*. (1980)and Kumar *et al.* (2013) also reported additive inheritance of this character in tomato.Parent P_1 in F_1 and P_3 in F_2 were identified as good general for higher acidity content and P_5 in F_1 and P_6 in F_2 for lower acidity.

Amongst, 14 and 20 significant crosses, noticed in F_1 and F_2, eight and nine had positive sca estimates, respectively. Of which two cross combinations *viz.,* P_1 x P_6 in F_1 and P_5 x P_7 in F_2 generationemerged as best crosses for fruit acidity. Theses crosses involved high x lowand low x high combining lines, respectively. Thus, crossing between medium x small fruit lines appears to be essential to get high acid fruit in the present study. Similar results were observed by Gaikwad *et al.* (2003) for correspondence for TSS content in tomato.

Carbohydrate content

In plants the main carbohydrates of nutritional value are glucose, fructose, sucrose, polysaccharides and starch. Ahmed *et al*. (2004) emphasized that sugar are an important qualitative trait that deserves due attention in the quality breeding programme especially in vegetables like tomato. Carbohydrates in vegetables are responsible for sweetness and flavour and supply about 110 K cal calories, which is about four to five per cent of daily requirement.As in the case of most of the other vegetables, tomato also has lower carbohydrate content. Chakrabarti (2001) reported 4.70 per cent carbohydrates 100 g^{-1} of tomato edible portion.

Significance of both gca and sca, greater proportion of 6^2gca and more than 0.50 estimates of predictivity ratio revealed importance of additive genetic variance in the inheritance of carbohydrate content in F_1 generation in present study.In general, the entire parents except P_1 in F_2 had significant gca effects in both generations. Its range varied from -0.222 (P_8) to 0.314 (P_2) and -0.265 (P_8) to 0.232 (P_6) in F_1 and F_2, respectively. The parent $P_2$was the best general combining line for this trait. Similarly, in cross combinations also parent P_2 contributed constantly with parent P_6 when *per se performance* of top ranking crosses combinations in F_1 and F_2 coupled with their respective sca estimates were considered together. Hence, heterosis can be employed in F_1 and as well as selection of desirable segregate can be followed in F_2 generation for improvement of carbohydrate content.

Protein content

Proteins serve as building blocks of living cells. The essential components of protein are the 20 amino acids. Ahmed *et al.* (2004) reported that the average protein content in vegetables is lower (2.5 g 100 g^{-1}), than the legumes (25 g 100 g^{-1}). However, the quality index of protein is rated high among common plant foods. Chakrabarti (2001) reported 1.1g proteins 100 g^{-1} of edible portion in tomato. The Indian Council of Medical Research (ICMR) recommended 55 g daily intake of protein for a man engaged in moderate work.

Data over both generations revealed importance of additive genetic variance in the inheritance of protein content in the present study. Nanda and Rao (1975) in sorghum and Sumberg (1978) in alfalfa reported similar results. Significant maximum gca effect in both generations was noted in parent P_8 (0.145 in F_1 and 0.092 in F_2). No relevance was noticed among gca and sca effect since none of the cross combinations displayed significant positive or negative sca estimates among 28 F_1s investigated under present study in F_2 generation. However, in F_2 generation all 28 crosses were significant. In that 18 crosses had sca effects in desirable direction. Among them the cross P_6 x P_7 (0.186) and P_2 x P_6 (0.117) had higher sca estimates in which former was significantly superior over the later hence identified as best specific cross. Thus there is enough scope for selection of desirable segregates in F_2 generation.

Table 1. Source and some diagnostic features of homozygous parental lines of tomatoes

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, 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.

Table 2 Analysis of variance for nutritional characters of tomatoes

Source	D.F.	Total soluble solids (⁰Brix)	Fruit acidity (%)	Carbohydrate content (%)	Protein content (%)	Ascorbic acid content (mg 100 g^{-1})	*Beta* carotene content (mg 100 g-1)	Potassium content (mg 100 g^{-1})	Lycopene content (mg 100g^{-1})	Fruit yield (kg plant^{-1})
Replications	2	3.00**	0.079**	1.61**	0.013	70.86**	0.0169	0.044**	222.46**	3.92**
Genotypes	64	1.16**	0.080**	0.90**	0.058**	105.36**	0.044**	0.036**	285.90**	0.38**
Parents	7	0.70**	0.067**	0.97**	0.03	48.23**	0.015**	0.040**	130.080**	0.12**
F_1s	27	0.98**	0.036**	0.65**	0.080**	97.77**	0.027**	0.026**	300.02**	0.34**
F_2s	27	1.52**	0.085**	1.14**	0.045**	124.90**	0.062**	0.041**	309.47**	0.41**
P Vs F_1	1	0.10**	0.004**	0.46**	0.088*	188.06**	0.122**	0.195**	417.93**	2.74**
P Vs F_2	1	0.39*	0.005**	0.76**	0.054	287.95**	0.266**	0.052**	41.28**	1.01**
Error	128	0.007	0.001	0.025	0.022	1.17	0.0034	0.0009	0.212	0.023

*, ** Significant at *P* <0.05 and 0.01, respectively

Table 3. Analysis of variance forgeneral combining ability for nutritional characters of tomatoes

Effect	Generation	d.f.	Total soluble solids (⁰Brix)	Fruit acidity (%)	Carbohydrate content (%)	Protein content (%)	Ascorbic acid content (mg 100 g^{-1})	*Beta* carotene content (mg 100g-1)	Potassium content (mg100g^{-1})	Lycopene content (mg 100 g^{-1})	Fruit yield (kg ha^{-1})
GCA	F_1	7	0.613**	0.054**	0.312**	0.047**	37.857**	0.027**	0.019**	252.515**	0.236*
	F_2	7	0.562**	0.039**	0.340**	0.029**	19.112**	0.027**	0.019**	252.515**	0.245**
SCA	F_1	27	0.223**	0.006**	0.255**	0.008**	29.746**	0.005**	0.010**	54.788**	0.098**
	F_2	27	0.413**	0.026**	0.372**	0.010**	44.352**	0.005**	0.010**	54.788**	0.095**
Error	F_1	70	0.004	0.001	0.001	0.009	0.395	0.001	0.001	1.536	0.011
	F_2	70	0.004	0.001	0.012	0.01	0.029	0.001	0.001	1.536	0.005
6^2 gca	F_1		0.609	0.053	0.311	0.038	37.462	0.026	0.018	250.979	0.225
	F_2		0.558	0.038	0.328	0.019	19.083	0.026	0.018	250.979	0.24
6^2 sca	F_1		0.219	0.005	0.254	0.001	29.351	0.004	0.009	53.252	0.087
	F_2		0.409	0.025	0.36	0.001	44.323	0.004	0.009	53.252	0.09
(Predictivity ratio)	F_1		0.736	0.914	0.55	1.027	0.561	0.867	0.667	0.825	0.721
	F_2		0.577	0.603	0.477	1	0.301	0.867	0.667	0.825	0.727

*, ** Significant at *P* <0.05 and 0.01, respectively

Table 4 Estimates of general combining ability effects in 8 parents of tomatoes

Parents	Total soluble solids (0Brix)		Fruit acidity (%)		Carbohydrate content (%)		Protein content (%)		Ascorbic acid content (mg 100 g-1)		Beta carotene content (mg 100 g-1)		Potassium content (mg 100 g-1)		Lycopene content (mg 100 g-1)		Fruit yield (t ha-1)	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F_2
GT 1 (P1)	0.217**	0.272**	0.111**	0.073**	-0.076**	-0.01	-0.03	-0.046**	0.32	-0.253**	-0.01	-0.037**	-0.027**	-0.042**	0.11	1.18	1.414*	4.033**
Pusa Ruby(P_2)	0.357**	0.326**	-0.029**	-0.068**	0.314**	0.206**	-0.03	-0.046**	0.462*	0.288**	-0.025**	0.02	0.052**	0.015**	7.754**	6.559**	6.111**	6.241**
H 24 (P_3)	0.001	-0.087**	0.105**	0.090**	-0.075**	-0.153**	-0.01	0.025**	1.425**	0.746**	-0.021*	-0.030**	0	-0.016**	0.16	0.92	3.111**	-1.241**
Ec 490190 (P_4)	-0.159**	-0.127**	-0.020**	-0.022*	0.185**	0.175**	-0.02	0.042**	-1.085**	0.169**	0.123**	0.142**	0.060**	0.031**	-10.140**	-6.669**	-2.148**	-3.204**
Arka Vikas (P_5)	-0.126**	-0.01	-0.080**	-0.01	-0.037**	-0.112**	-0.03	-0.062**	-2.825**	-1.995**	-0.01	-0.02	0.031**	0.033**	-1.614**	-0.04	0.51	0.46
Ec 163599 (P_6)	0.065**	0.163**	-0.066**	-0.073**	0.052**	0.232**	-0.083**	-0.054**	1.606**	1.858**	-0.037**	-0.035**	-0.056**	0.001	3.107**	0.06	-2.274**	-3.759**
Ec 177371 (P_7)	0.092**	-0.179**	0.022**	0.046**	-0.142 **	-0.073*	-0.02	0.022**	2.541**	1.157**	0.01	0.001	-0.042**	0.001	-0.5	-0.76	-3.443**	-0.951*
Ec 398704 (P_8)	-0.448**	-0.361**	-0.043**	-0.033**	-0.222**	-0.265**	0.145**	0.092**	-2.442**	-1.969**	-0.035**	-0.043**	-0.015*	-0.019**	1.124**	-1.25	-3.281**	-1.582**
S E Gi-Gj	0.0182	0.0184	0.0067	0.0094	0.0042	0.0319	0.05	-0.021**	0.1859	0.0505	0.0095	0.0091	0.0064	0.0011	0.3666	0.6813	0.6754	0.4644

*,** significant at 5 % and 1 % level, respectively

P_1 - GT 1, P_2 - Pusa Ruby , P_3 - H 24, P_4 - Ec 490190, P_5 - Arka Vikas, P_6 - Ec 163599, P_7 - Ec 177371, P_8 - Ec 398704

Table 5 Estimates of specific combining ability (SCA) effects for different nutritional traits of 28 F_1 and F_2 crosses of tomatoes

Crosses	Total soluble solids (°Brix)		Fruit acidity (%)		Carbohydrate content (%)		Protein content (%)		Ascorbic acid content (mg 100 g-1)		*Beta* carotene content (mg 100 g-1)		Potassium content (mg 100 g-1)		Lycopene content (mg 100 g-1)		Fruit yield (Kg plant-1)	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_1	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
P_1 X P_2	-0.435**	-0.493**	0.026	-0.099**	-1.399**	-1.334**	0.008	0.038**	-3.358**	-9.868**	-0.044	-0.093**	-0.11	-0.196**	4.622**	7.214**	5.432**	0.282**
P_1 X P_3	0.233**	-0.08	-0.077**	-0.207**	-0.007	-0.012	0.052	0.060**	-1.677*	-3.712**	-0.041	-0.043*	0.099**	0.079**	14.390**	15.671**	2.909	-0.438**
P_1 X P_4	0.081	0.960**	-0.047*	0.168**	0.173**	0.310**	-0.017	0.125**	0.895	4.079**	0.061*	-0.005	-0.05	-0.079**	5.326**	4.749**	-13.81**	-0.849**
P_1 X P_5	0.448**	0.240**	0.057*	0.02	0.186**	0.157	-0.029	-0.013**	-2.478**	-0.371*	0.048	0.143**	0.056**	0.066**	-4.454**	-5.287**	-3.905*	-0.373**
P_1 X P_6	-0.943**	-1.124**	0.113**	-0.191**	0.466**	0.203*	0.1	0.030**	-3.902**	-9.634**	0.035	0.039	-0.060**	-0.025**	-2.905**	-3.039	3.229	-0.066
P_1 X P_7	1.243**	1.412**	-0.045*	-0.110**	0.091**	0.634**	0.09	-0.093**	20.71**	18.11**	0.085**	0.027	0.022	-0.066**	4.764**	1.787	-0.05	-0.357**
P_1 X P_8	-0.03	-0.206**	0.040*	0.096**	0.481**	0.190**	-0.13	-0.116**	-6.164**	2.010**	0.045	0.057*	-0.040**	0.012**	-8.671**	-4.881**	10.176**	0.179**
P_2 X P_3	-0.184**	-0.135*	0.016	-0.099**	0.003	0.042	0.059	-0.030**	-0.019	-0.646**	0.024	0.087**	-0.110**	-0.089**	1.518	-6.238**	-3.442	0.036
P_2 X P_4	0.044	0.176**	0.093**	0.266**	-0.017	0.427**	-0.153	0.011**	1.751**	5.941**	0.03	-0.002	-0.050*	0.031**	8.702**	5.292**	6.093**	-1.199**
P_2 X P_5	-0.259**	0.385**	0.094**	-0.192**	0.289**	0.540**	0.081	0.046**	2.427**	3.898**	0.113**	0.186**	0.044*	0.069**	2.748*	-1.34	1.821	0.001
P_2 X P_6	0.850**	1.218**	0.069**	0.117**	0.756**	0.867**	-0.106	0.117**	2.767**	7.258**	-0.02	0.008	0.181**	-0.073**	-0.819	-0.682	-1.993	0.558**
P_2 X P_7	-0.178**	-1.236**	-0.189**	-0.252**	0.081**	-0.562**	0.05	0.017**	-4.678**	-2.860**	0.014	0.106**	0.197**	0.256**	7.907**	8.107**	-4.815**	0.450**
P_2 X P_8	0.249**	-0.06	0.107**	0.077**	-0.119**	-0.926**	0.161	0.073**	-1.498**	-8.151**	0.047	0.103**	-0.040*	-0.112**	1.841	8.246**	-11.45**	-0.267**
P_3 X P_4	0.829**	0.719**	-0.01	-0.059*	0.382**	0.432**	0.114	0.037**	3.431**	-2.330**	0.026	-0.122**	0.023	-0.065**	2.429*	0.91	-3.25	-0.579**
P_3 X P_5	-0.374**	-0.595**	-0.01	-0.036	0.275**	-0.471**	-0.021	0.049**	-4.949**	-4.373**	0.001	0.029	0.108**	0.050**	-3.301**	2.591	-10.49**	-0.149**
P_3 X P_6	0.435**	0.628**	0.006	-0.081**	-0.015	0.146**	-0.082	0.059**	-0.563	3.194**	0.053	0.111**	-0.080*	-0.092**	-0.639	-0.238	8.231**	-0.562**
P_3 X P_7	-0.292**	-0.423**	0.021	0.104**	-0.120**	-0.310**	0.044	0.083**	-2.998**	-5.121**	0.120**	0.136**	-0.002	-0.003	-3.363**	5.382*	10.882**	-0.087*
P_3 X P_8	-0.116*	-0.044	-0.103**	-0.081**	-0.280**	-0.011	-0.105	0.066**	-2.564**	-0.192	0.004	0.016	0.047*	0.075**	-1.525	-6.689**	6.718**	1.576**
P_4 X P_5	-0.276**	-0.358**	-0.096**	-0.115**	-0.335**	-1.029**	0.096	-0.027**	0.631	-3.796**	0.095**	0.177**	0.046*	0.022**	-6.984**	-1.329	-6.550**	1.290**
P_4 X P_6	-0.167**	-0.332**	-0.007	-0.150**	0.335**	0.381**	0.056	-0.153**	0.207	1.968**	0.075**	0.216**	0.067**	-0.019**	-10.240**	-6.821**	5.190**	0.314**
P_4 X P_7	-0.195**	-0.582**	0.032	-0.225**	0.560**	0.608**	-0.035	0.057**	-5.238**	-0.937**	0.012	0.131**	0.129**	0.103**	-10.200**	-9.778**	22.195**	-0.838**
P_4 X P_8	-0.155**	-0.400**	0.021	-0.149**	0.360**	0.184	-0.024	-0.123**	-2.058**	-1.418**	0.039	0.084**	0.015	-0.002	-10.260**	-1.519	-3.34	1.242**
P_5 X P_6	-0.367**	-0.649**	-0.019	0.176**	-0.152**	-0.092	-0.077	0.069**	1.643**	-0.075	-0.001	-0.126**	-0.050*	0.192**	9.179**	3.877	-0.093	-0.377**

P_1 - GT 1, P_2 - Pusa Ruby , P_3 - H 24, P_4 - Ec 490190, P_5 - Arka Vikas, P_6 - Ec 163599, P_7 - Ec 177371, P_8 - Ec 398704

*,** significant at 5 % and 1 % level, respectively

Ascorbic acid content

The antioxidant potential of tomato is derived from a mixture of antioxidant biomolecules, including lycopene, ascorbic acid, phenolics, flavonoids and vitamin E, and is especially high in cherry tomatoes (Kaur *et al.*2004). For ascorbic acid content additive inheritance was noted since 6^2gca> 6^2sca and predictivity ratio had > 0.50 estimates in F_1 generation. Similarly Patil (1985), Bhatt *et al.* (2004) and Kumar *et al*. (2013) reported importance of additive genetic variance in inheritance of ascorbic acid content in tomato. The study indicated that comparatively small fruited parents P_7, P_6, P_3 and P_2 indicated significant stable positive gca effects both in F_1 and F_2 generations. Twenty two crosses revealed significant sca effects in F_1 and 26 in F_2 generation. The crosses, P_1 x P_7, P_2 x P_6were found to be constantly good on the basis of sca effects in F_1 and F_2 generations.These crosses had medium x high and high x high combining lines, respectively.

Beta carotene content

Colour is a major quality characteristic in virtually all fruits and vegetables and uniformity of colour within tomatoes is a principal requirement of quality standards for this crop. In the present study,all the parents except P_1 in F_1, P_2 in F_2 and P_5 and P_8 in both sets had significant gca effects. The range of effect varied from -0.037 (P_6) to 0.123 (P_4) and -0.043 (P_8) to P_4 (0.142) in F_1 and F_2 generations, respectively. Parent P_4 recorded highest positive significant effect in both the generations, suggesting stability for combining ability for this trait. The importance of fixable gene effect was experienced in both generations in the inheritance of β carotene content. Nanda and Rao (1975) and Synkova *et al*. (1997) also reported that β carotene content was inherited by additive genetic variance in F_1 generation.

Eight and 20 crosses had significant estimates due to specific combining ability in F_1 and F_2, respectively. As many as 12 crosses in F_2 and six in F_1 had significantly positive sca value. However, only four crosses *viz.,* P_3 x P_7, P_2 x P_5, P_4 x P_6 and P_4 x P_5 exhibited significant positive and stable sca effects over the generations. In that former most cross recorded highest sca effects therefore was regarded as specific cross in both sets. However the cross P_4 x P_5 involving high x medium combining lines had the constant expression of β carotene content, hence, it can be exploited in both generations, for higher β carotene content.

Table 6: Top three parents identified based on *per se* (parenthesis) and gca effects of tomatoes

Character	Best parent *per se performance*	Best parent for gca F_1	Best parent for gca F_2	Common parent on *per se performance* and gca effects in both F_1 and F_2 generations
Total soluble solids (0Brix)	P_2 (5.61)	P_2 (0.357)	P_2 (0.326)	P_2
	P_5 (5.38)	P_1 (0.217)	P_1 (0.272)	
	P_6 (5.33)	P_7 (0.092)	P_6 (0.163)	
Fruit acidity (%)	P_3 (1.330)	P_1 (0.110)	P_3 (0.090)	P_3
	P_1 (1.00)	P_3 (0.105)	P_1 (0.073)	P_1
	P_7 (0.91)	P_7 (0.022)	P_7 (0.046)	P_7
Carbohydrate (%)	P_2 (4.21)	P_2 (0.314)	P_6 (0.232)	P_2
	P_5 (3.66)	P_4 (0.185)	P_2 (0.260)	
	P_1 (3.23)	P_6 (0.052)	P_3 (0.175)	
Protein (%)	P_7 (1.04)	P_8 (0.145)	P_8 (0.092)	P_8
	P_8 (0.96)	P_3 (-0.01)	P_4 (0.042)	
	P_6 (0.87)	P_7 (-0.02)	P_3 (0.025)	
Ascorbic acid content (mg 100 g^{-1})	P_7 (35.00)	P_7 (2.541)	P_6 (1.857)	P_7
	P_3 (34.74)	P_6 (1.606)	P_7 (1.157)	P_3
	P_6 (33.99)	P_3 (1.425)	P_3 (0.746)	P_6
Beta Carotene (mg 100 g^{-1})	P_4 (0.39)	P_4 (0.123)	P_4 (0.142)	P_4
	P_7 (0.33)	P_5 (0.001)	P_7 (0.001)	
	P_5 (0.24)	P_1 (-0.010)	P_2 (0.020)	
Potassium content (g 100 $g^{-1)}$	P_2 (0.54)	P_4 (0.060)	P_5 (0.033)	P_2
	P_4 (0.52)	P_2 (0.052)	P_4 (0.031)	P_4
	P_1 (0.48)	P_5 (0.031)	P_2 (0.015)	
Lycopene content (mg 100 g^{-1})	P_6 (45.84)	P_2 (7.754)	P_2 (6.559)	P_2
	P_8 (44.57)	P_6 (3.107)	P_1 (1.180)	
	P_2 (41.28)	P_8 (1.124)	P_3 (0.920)	
Fruit yield (kg plant $^{-1}$)	P_1 (1.14)	P_2 (6.111)	P_2 (6.241)	P_1
	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)	

P_1 - GT 1, P_2 - Pusa Ruby , P_3 - H 24, P_4 - Ec 490190, P_5 - Arka Vikas, P_6 - Ec 163599, P_7 - Ec 177371, P_8 - Ec 398704

Table 7. Top ranking higher yielding ten crosses on the basis of *per se performance*of tomatoes

Cross combination		*Per se performance*		Sca effect		Gca effect of parent in F_1		Gca effect of parent in F_2		Significant sca effect for other characters	
F_1	F_2	F_1	F_2	F_1	F_2	Female	Male	Female	Male	F_1	F_2
P_1 x P_3	P_2 x P_3	44	45	14	10	1	3	6	-1	1,2,8,9	1, 7
P_2 x P_3	P_1 x P_2	43	42	8	4	6	3	4	6	1	1,5,9
P_2 x P_5	P_2 x P_5	42	35	9	-4	6	1	6	0	1,3,4,5,6, 7, 8,9	1,2,3,4,5, 6,9
P_2 x P_6	P_1 x P_4	37	34	7	-20	6	-2	4	-3	1,2,3,4,6,8	1,2,3,4,5,6,9
P_2 x P_7	P_2 x P_7	36	32	7	1	6	-3	6	-1	1,4,8,9	1,5,7,8,9
P_1 x P_2	P_1 x P_8	35	29	-1	4	1	6	4	-2	9	1,3,4
P_3 x P_5	P_2 x P_8	34	29	4	-17	3	1	-1	0	1,4,8	1,3,5,7,9
P_3 x P_8	P_6 x P_7	31	28	5	-1	3	-3	-4	-1	1,8	1,3,5,8
P_5 x P_6	P_1 x P_6	29	28	5	10	1	-2	0	-4	1,6,9	1,4,5
P_3 x P_6	P_5 x P_7	28	29	2	-3	3	-2	-1	-4	2	1,9
1 Fruit yield (kg plant^{-1}) 2 Total soluble solids (^{0}Brix) 3 Fruit acidity (%)				4 Carbohydrate content (%) 5 Protein content (%) 6 Ascorbic acid (mg 100 g^{-1})						7 *Beta* carotene (mg 100 g^{-1}) 8 Potassium content(g 100 g^{-1}) 9 Lycopene content (mg 100 g^{-1})	

P_1 - GT 1, P_2 - Pusa Ruby , P_3 - H 24, P_4 - Ec 490190, P_5 - Arka Vikas, P_6 - Ec 163599, P_7 - Ec 177371, P_8 - Ec 398704

Potassium content

An examination of data pertaining to gca effects revealed that parents P_4, P_2 and P_5 exhibited positive and significant gca effects in both the sets for potassium content. Potassium content was found to be inherited by additive genetic variance which hasearlier been reported by Sleper *et al.* (1977), Das *et al.* (1984) and Spehar (1995).Estimate of sca effects indicated that 21 and 26 crosses had significant effects in F_1 and F_2, respectively. Out of these significant crosses, 13 and 14 had positive sca effect in the F_1 and F_2, respectively. The cross P_2 x P_7 recorded the maximum positive stable sca estimates among nine stable performing crosses over the generations. However, the cross P_2 x P_7 was significantly superior to the rest hence, was considered as the best specific cross in the present investigations.

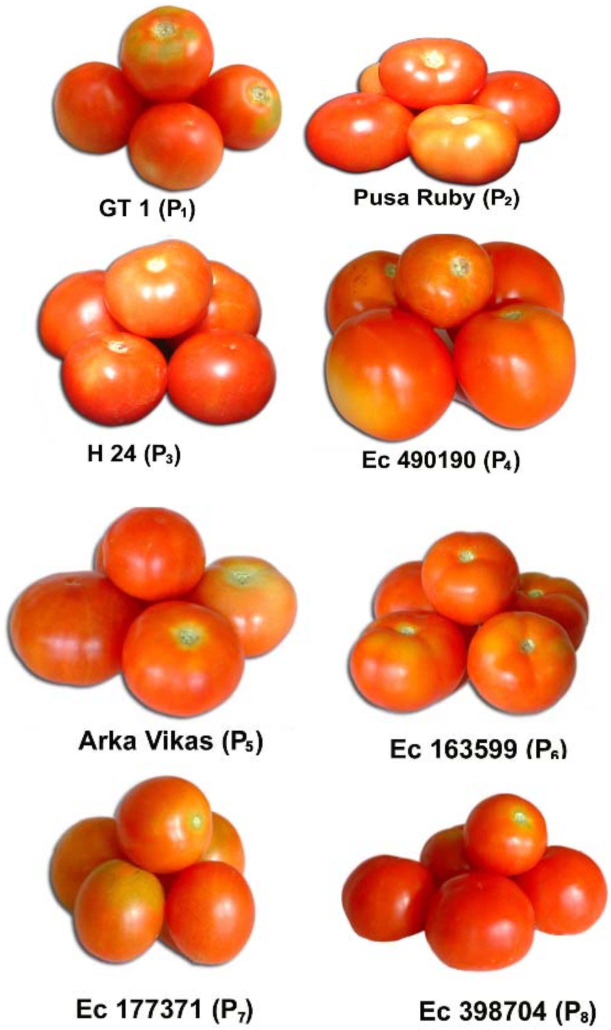

Fig-1: parents used in the study

Lycopene content

Thelycopene predominates among carotenoids and is mainly responsible for the red colour of tomato fruits and their derived products (Valverde *et al*. 2002).Lycopene content and antioxidant activity of tomatoes varies between cultivars and is highest in cherry or small, cocktail fruit (Kaur *et al.*2004). For the consumer, it is important to know that 52% of the total antioxidants (48% lycopene, 43% ascorbic acid, 53% phenolics) are located in the epidermis of the fruit, which in consequence should not be discarded during consumptionsince it combats free radicals that damage living tissues progressively (Khan *et al*. 2004). As in the present study Kumar *et al*. (2013) also reported additive inheritance of lycopene content. However Bhutani *et al*. (1983), Kumar *et al*. (1997) and Roopa *et al*. (2001) reported importance of non additive genetic variance for this trait. The gca effects varied from -10.140 (P_4) to 7.754 (P_2) and -6.669 (P_4) to 6.559 (P_2) in F_1 and F_2, respectively. Estimates of gca effects in both the generations indicated that parents P_2, $P_6$and P_8 were good general combiners for lycopene content in F_1, however, former most parent was statistically superior to later parents hence was considered as best general combiner in F_1. However, considering both sets of data, parents P_2 was considered as best general combiner in both first and second fillial generations.

Estimates of sca effects revealed that 22 and 16 crosses had significant sca estimates in both generations, respectively. Among the significant crosses proportion of significant positive crosses was higher than significant negative sca effects in F_1 while in F_2 equal proportion noticed. The sca estimates ranged from -10.260 (P_4 x P_8) to 14.390 (P_1 x P_3) and -9.778 (P_4 x P_7) to 15.671 (P_1 x P_3) in F_1 and F_2 generations, respectively. Considering both sets, six crosses expressed significant positive stable sca effects, of which the cross P_1 x P_3 was statistically superior.

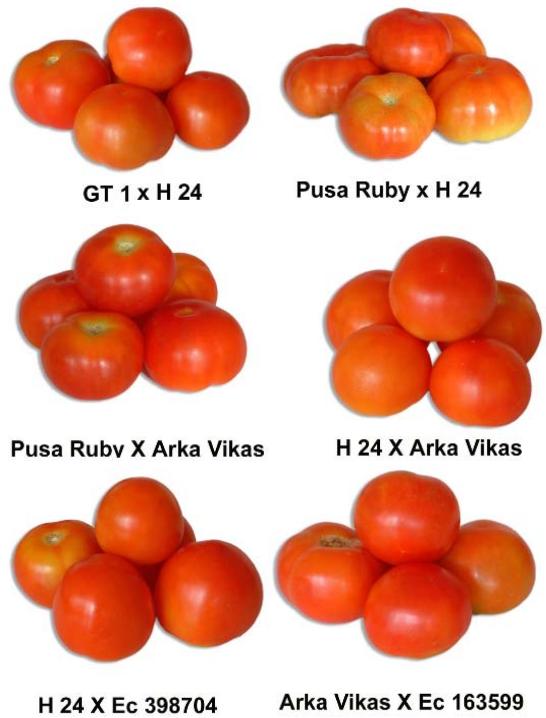

Fig-2: Crosses desirable for yield

Fruit yield

For fruit yield plant^{-1}, significance of variances due to both general and specific combining ability revealed as well as predictivity ratio indicated importance of non fixable gene effects for fruit yield plant^{-1} in the present study (Singh and Asati 2011, Shende *et al*. 2012 and Yadav *et al*. 2013) in F_1 generation and with Singh and Mital (1978) and Peter and Rai (1980) in F_2 generation. Perusal of *per se performance* of parents and their gca effects in F_1 and F_2 revealed that, parent P_2 appeared to be best general combiner for total soluble solids, carbohydrates, lycopene, and yield in both sets (Table 6). The crossGT 1 x H 24cross involving high x high combiners could be considered as best cross over the generations when higher yield is desired.Perusal of data in table 7 revealed that the cross Pusa Ruby x Arka Vikas was desirable for fruit yield as well as nutritional characters sinceit inherited all nutritional traits except TSS content in F_1generation and carotene content in F_2 generation as opined by Dias (2012 c). This cross involvedhigh x high combining lines for potassium, high x low combining lines for TSS, carbohydrate and vitamin C content, medium x lowfor lycopene, medium x medium for protein content and low x low combining lines for fruit acidity content. As observed in the present study, Kavita *et al*. (2007) also found that the sca effect did not always coincide with the ranking based on per se performance.

CONCLUSION

Estimates of combing ability analysis indicated that variances due to both general combining ability (gca) and specific combing ability (sca) were significant for all the characters. The estimates of predictivity ratio = $\frac{2\sigma^2 gca}{2\sigma^2 gca + \sigma^2 sca}$ indicated high magnitude of non additive gene action for almost all traits indicting exploitation of heterosis breeding. Estimation of gca effects indicated that none of the parents was high general combiner for all characters under present study. However parents GT 1 and Pusa Ruby were the best general combiner for fruit yield and TSS content over the generations. Exotic parent Ec 490190 was good general combiner for carbohydrate, β carotene and potassium content in both generations. For exploitation of hybrid vigour the performance of the parent H 24 was the best in F_1 generation for fruit yield, TSS and potassium content.

The parent Ec 163599 was best for lycopene, protein and potassium content indicating its feasibility of exploitation on commercial scale. The cross GT 1 x H 24 depicted highest sca effect for fruit yields and the cross Pusa Ruby x Arka Vikas was desirable for nutritional characters (Plate 2). Present study revealed that although exotic and domesticated parents had better nutritional quality content, their inheritance in $F_1$and F_2 was partially expressed. Hence selection of desired plant type in segregating generations may be adopted.

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