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ESTIMATES OF HYBRID VIGOUR AND INBREEDING DEPRESSION FOR FRUIT NUTRITIONAL CHARACTERS IN TOMATO

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Abstract: A set of 28 crosses were generated by crossing 8 inbred lines of tomato namely Gujarat Tomato 1 (GT 1), Pusa Ruby, H 24, Ec 490190, Arka Vikas, Ec 177371, IC89976 and Ec 398704. Parents, their F_1 hybrids and F_2 populations were evaluated in randomized complete block design with three replications. Data were recorded on total soluble solids, total titrable acidity, carbohydrates, proteins, carotenoids, ascorbic acid, potassium, lycopene and fruit yieldat Junagadh Agricultural University, Junagadh. Significant genetic differences were observed among the parents, their F_1 hybrids and F_2 populations for all characters except protein content under study.

The cross GT 1 x H 24 followed by GT 1 X Ec 490190 and Pusa Ruby X Ec 163599 exhibited higher heterobeltiosis as well as standard heterosis along with considerable inbreeding depression for nutritional charactersalongwith yieldhence, can be recommended for breeding improved nutritional lines in future.

Keywords: Heterosis, inbreeding depression, F_1 hybrids, F_2 population, tomato, nutritional quality.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a major horticultural crop with an estimated global production of over 159 million metric tons from an area of 4.73 million hawith a productivity of 33.52 t ha^{-1} (F.A.O. 2011). India is the second largest tomato producer of the world after China, accounting for about 11% of the world tomato production. During 2010-11, the area and production of tomato in India was about 0.865 million hectare and 16.82 million tonnes, with an average productivity 19.6 tha^{-1} (Indian Horticulture Database, 2011). Tomato is universally treated as 'Protective Food' since it is a rich of minerals, vitamins, antioxidants and organic acids. Apart from contributing nutritive elements, colour and flavour to the diet, tomatoes are also a valuable source of antioxidants, or chemo-protective compounds, and may thus be termed a "functional food" (Ranieri *et al.* 2004). The antioxidant potential of tomato is derived from a mixture of antioxidant biomolecules,

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including lycopene, ascorbic acid, phenolics, flavonoids and vitamin E (Kaur *et al.*2004). Tomato being a moderate nutritional crop is considered as a important source of Vitamin A and C and minerals which are important ingredients for table purpose, sambar preparation, chutney, pickles, ketchup, soup, juice puree etc.

The nutrition importance of the tomato indicates there is need to formulate breeding programme and to develop cultivars rich in vitamins, nutrients and oxidants, processing traits with high quality of fruit as well as yield. The replacement of inbred lines by hybrids has remarkably increased yield, while the genetic gain rate has been reduced due to low genetic diversity within cultivated tomatoes (Grandillo *et al*. 1999). Within cultivated tomato, genetic variation is very low; thus, there has long been an interest in searching for genes in exotic and primitive germplasm. Tomato landraces are still cultivated for local use and consumption in many regions of the world. They frequently have distinctive organoleptic traits (flavour and aroma) and nutritional value. Diallel breeding strategies permit an in depth study and effective exploitation of the genetic diversity of wild relatives and landraces.

It is costly to produce hybrid seeds every year by artificial emasculation and pollination. The study of extent of heterosis in F_1 over better parent provide an indication about the type of gene action and significance of inbreeding depression in F_2 indicates the presence of non additive gene effects. Possibilities of using F_1 seeds to raise F_2 in tomato had been reported by Larson and Currence (1944) and Choudhary *et al.* (1965) with the hybrid retaining heterosis in F_2 generation. With these backdrops, present investigations was undertaken to develop hybrids having better yield coupled with superior nutritional quality to obtain information on the genetic makeup of quantitative characters in tomato through heterobeltiosis and inbreeding depression.

MATERIALS AND METHODS

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 (Ec177371) and P_8 (Ec 398704) which were crossed in half diallel fashion to get F_1 seeds. 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 (mg 100 g^{-1}), proteins (%), carotenoids (mg 100 g^{-1}), ascorbic acid (mg 100 g^{-1}), potassium (g 100 g^{-1}) and lycopene (mg 100 g^{-1}) and fruit yield Kg $plant^{-1}$. Heterosis over better parent (BP) as per Fonseca and Patterson (1968) was calculated, while standard heterosis (SH) using Junagadh Ruby variety as standard check was calculated as per Meredith and Bridge (1972). Inbreeding depression (ID) from F_1 to F_2 was calculated by the formula, ID (%) = $[(F_1 – F_2) / F_1] \times 100$ where F_2 denotes the mean of F_2 population for a trait.

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). Data were compiled for analysis of variance for all these traits using method suggested by Panse and Sukhatme (1987).

RESULTS AND DISCUSSION

Analysis of variance revealed (Table 1) highly significant differences among the genotypes, parents and hybrids for all the characters except protein content indicating the presence of significant variation among the genotypes as well as crosses studied. This emphasized the need of selecting parents for maximization of hybrid vigour with respect to nutritional traits. Considerable genetic variation for various traits including fruit yield have been reported by Kanthaswamy and Balakrishnan (1989) and Zhou and Xu (1990). The mean sum of squares for parentsvs F_1s were also found significant for all traits which indicated presence of substantial amount of heterosis in all cross combinations. The mean square due to F_1s vs. F_2s revealed that the F_1s differed significantly from their F_2s for all character except protein content suggesting the presence of considerable amount of inbreeding depression in F_2s.

Table 1 Analysis of variance (mean sum of squares) for fruit nutritional traits in 8 x 8 diallel set of tomato

Source	D. F.	Total soluble solids (^{0}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 $plant^{-1}$)
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 5 % level

** Significant at 1 % level

The mean performance, various heterotic effects and inbreeding depression as well as promising crosses identified for the characters studied are presented in Table 2. The range of mean performance was wide for all characters except fruit acidity content. All the crosses exhibited wide range as compared to their parents for almost all the traits in both generations. Various heterotic effects were medium to high for all characters in both directions. The crosses with high heterotic effects for characters under study in general also showed inbreeding depression, suggesting that heterosis was mainly due to non additive gene action. However, some F_2s expressed considerable improvement due to inbreeding, indicating feasibility of developing stable lines and or transgressive segregants.

Total soluble solids

Estimates of heterobeltiosis and standard heterosis for this trait ranged from -19.76 to 24.57 and -47.68 to 27.01 per cent, respectively (Table 2). The cross GT 1 x Ec177371 recorded highest BH as well as SH estimates and negative ID estimates. These findings are in conformity with Kanthaswamy and Balakrishnan (1989), Zhou and Xu (1990) and Joshi *et al.* (2005) who have also observed various heterosis estimates.

Table 2: Range of *per se* performance, heterobeltiosis (BP), standard heterosis (SH), inbreeding depression (ID), along with most heterotic crosses and inbreeding depression for fresh fruit nutritional traits in 8 x 8 diallel set of tomato

Characters	Range						Better parent based on *per se* performance	Number of hybrids with significant heterosis and inbreeding depression						Best cross combination on *Per se*performance		Best hybrid with maximum		
	Per se performance			Heterosis		ID (%)		Over BH		Over SH		ID				Heterosis effect over		Inbreeding Depression
	Parents	Crosses		BH (%)	SH (%)			+ve	-ve	+ve	-ve	+ve	-ve	F_1	F_2	BH	SC	
		F_1	F_2															
TSS (^{o} Brix)	4.21 to 5.61	4.18 to 6.49	4.00 to 6.59	-19.76 to 24.57	-47.68 to 27.01	-17.99 to 27.13	P_2 (5.61) P_5 (5.38)	3	21	16	6	18	7	P_1 x P_7 (6.49)	P_2 x P_6 (6.59)	P_1 x P_7 (24.57)	P_1 x P_7 (27.01)	1.54

Fruit acidity (%)	0.65 to 1.10	0.60 to 0.97	0.42 to 0.93	-7.67 to -40.00	13.61 to 52.88	-20.51 to 59.56	P_3 (1.330) P_1 (1.00)	0	26	24	0	22	3	P_1 x P_6 (0.97)	P_3 x P_7 (0.93)	NA	P_1 x P_6 (52.88)	48.29
Carbohydrate (%)	2.80 to 4.21	2.21 to4.50	2.18 to 4.18	-47.39 to 31.56	-29.21 to 43.82	-19.30 to 30.18	P_2 (4.21) P_5 (3.66)	13	14	22	6	5	4	P_2 x P_6 (4.50)	P_2 x P_6 (4.63)	P_1 x P_7 (-19.30)	P_4 x P_6 (31.56)	-2.89
Protein (%)	0.79 to 1.04	0.70to 1.22	0.70 to 1.20	-29.67 to -31.0	30.12 to 46.59	-42.60 to 32.36	P_7 (1.04) P_8 (0.96)	0	2	3	0	2	2	P_7 x P_8 (1.22)	P_6 x P_7 (1.20)	NA	P_7 x P_8 (46.59)	24.93
Ascorbic acid (mg 100 $^{g-1}$)	24.65 to 35.00	18.94 to 50.79	15.03 to 45.68	-47.39 to 31.56	-29.21 to 43.82	-39.65 to 35.13	P_7 (35.00) P_3 (34.74)	13	14	22	6	7	6	P_1 x P_7 (50.79)	P_1 x P_7 (45.68)	P_4 x P_6 (31.56)	P_2 x P_6 (43.82)	10.06
Beta carotene (mg 100 $^{g-1}$)	0.18 to 0.39	0.35 to 0.42	0.14 to 0.67	-29.67 to -31.0	46.59 to 46.59	-33.33 to 31.03	P_4 (0.39) P_7 (0.33)	0	2	1	0	4	5	P_4 x P_5 (0.52)	P_4 x P_6 (0.67)	NA	P_7 x P_8 (46.59)	-5.77
Potassium (mg 100 $^{g-1}$)	0.21 to 0.54	0.35 to 0.70	0.23 to 0.73	-57.33 to 15.95	-25.18 to 35.97	-63.20 to 44.00	P_2 (0.54) P_4 (0.52)	1	21	10	3	13	3	P_2 x P_7 (0.70)	P_2 x P_7 (0.73)	P_3 x P_5 (15.95)	P_7 x P_8 (46.59)	28.33
Lycopene (mg 100 $^{g-1}$)	29.37 to 45.84	18.18 to 54.19	21.25 to 56.22	-55.69 to 55.20	46.04 to 60.74	-49.94 to 36.21	P_6 (45.84) P_8 (44.57)	9	10	18	4	15	13	P_2 x P_7 (54.19)	P_1 x P_3 (56.22)	P_1 x P_3 (55.20)	P_2 x P_7 (60.74)	3.36
Fruit yield (Kg plant^{-1})	0.57 to 1.14	0.81 to 1.99	0.50 to 2.01	30.67 to 98.67	-28.53 to 75.29	-29.47 to 46.64	P_1 (1.14) P_2 (1.09)	11	0	1	8	5	12	P_4 x P_8 (0.60)	P_4 x P_8 (0.74)	P_2 x P_3 (78.69)	P_1 x P_3 (75.30)	46.64

P_1- GT1 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

Fruit acidity

The heterobeltiosis estimates varied from -7.67 to -40.00 percent. The cross GT 1 x Ec 163599recorded highest *per se* performance as well as RH estimates. Patil and Patil (1988) and Kanthaswamy and Balakrishnan (1989) found heterosis estimates in both directions. The native parent GT 1, contributed significantly towards improvement of acidity in combination with indigenous or exotic parents. The crosses, which had higher heterosis estimates also registered higher ID value indicating that heterosis phenomenon remains confined to F_1 generation only. As compared to F_1, seven crosses registered increase in acidity content in F_2 generation. The crosses GT 1 x Ec 490190, Pusa Ruby x Arka Vikas and Arka Vikas x Ec 398704 which had negative or non significant heterotic effect in F_1 also expressed negative ID value in F_2. Kanthaswamy and

Balakrishnan (1989), Okasha *et al.* (2001) and Pandey and Dixit (2001) also reported ID for fruit acidity.

Carbohydrate content

The estimates of BH and SH for this trait ranged from -47.39 to 31.56 and -29.21 to 43.82 per cent, respectively (Table 2). These findings are in line with that of Zeng and Cao (1997) for positive heterosis and with Ciofu *et al* (1970) for negative heterosis. Maximum BH was observed in the cross Ec 490190 x Ec 163599 followed by Ec 490190 x Arka Vikas and H 24 x Ec 398704. Twenty two crosses exhibited improvement over check variety Junagadh Ruby. The extent of inbreeding depression varied from -19.30 to 30.18 %. Georgelis *et al.* (2004) also observed significant differences in F_1 and F_2 generation thereby inbreeding depressions for carbohydrate content and or carbohydrate contributing parameters. The cross Pusa Ruby x Ec 163599 exhibited better *per se* performance in F_1 and F_2 as well as heterosis estimates, hence, is desired in both generations.

Protein content

The heterobeltiosis estimates were negatively significant in two crosses *viz.,* Arka Vikas x Ec 163599 and Pusa Ruby x Ec490190 (Table 2). However, the cross Ec177371 x Ec 398704 had significantly higher RH estimates indicating presence of favourable genes for protein content, among the parents involved in these crosses. Lawrence *et al.* (1987) reported significant positive heterosis for protein content in pea. Of the four significant crosses, an equal number of crosses recorded positive and negative ID value for protein content which indicated prevalence of inbreeding depression in both directions (Lawrence*et al.*1987).

Ascorbic acid

Thirteen and 22crosses had positive BH and RH estimates, respectively (Table 2) in the present study. Patil and Patil (1988), Kanthaswamy and Balakrishnan (1989) and Joshi *et al.* (2005) also reported heterosis for this trait in both directions. The cross Ec 490190 x Ec 163599 had the highest BH estimates revealing that, at least one small fruited parent was responsible for heterotic effect. Stevens (1986) also observed an inverse relationship between high ascorbic acid and large fruit size probably because the vitamin C level of tomato fruit was increased by light and its more accumulation near the skin. Like heterosis, residual heterosis was also observed in both direction having moderate magnitudes. These findings are in agreement with those of Bhutani (1981), Kanthaswamy and Balakrishnan (1989) and Pandey and Dixit (2001). On *per se* performance basis the ascorbic acid content of cross Pusa Ruby x Ec 163599 was increased from 32.06 mg $100g^{-1}$ in F_1 to 36.07 mg 100^{-1} in F_2. Thus, considering average fruit weight (42.56 g) in F_1 and

(59.00 g) in F_2 generation; consuming three to four fruits daily, can meet daily requirement of vitamin C of a person engaged in moderate work. Hence, the cross Pusa Ruby x Ec 163599 may be exploited commercially when high ascorbic acid is desired. Wagh *et al.* (2006) also reported higher amount of ascorbic acid in 'Selection 47'.

***Beta* carotene**

Deposition of carotenoid pigments is responsible for the characteristic colour of ripe tomatoes (Fraser *et al.*2001). For *beta* carotene the cross Ec 177371 x Ec 398704 recorded 49.59 per cent standard heterosis, hence, preferred over check variety Junagadh Ruby (Table 2).A negative estimate for heterobeltiosis signifies non additive gene action in the inheritance of this trait Chen and Zhao (1990). Thus, although parents in the present study had considerable variation for β carotene content, but their expression was not complete in F_1 generation. On *per se* performance basis the cross Ec 490190 x Arka Vikas had highest (0.52 mg 100 g^{-1}) β carotene content followed by Pusa Rubyx Ec177371 (0.48 mg 100 g^{-1}) and Ec 490190 x Ec 163599 (0.48 mg 100 g^{-1}) indicating that parent Ec 490190 having high β carotene content could be exploited for high β content in future crop improvement programme. The extent of inbreeding depression was moderate in magnitude in both directions. Five and four crosses exhibited decrease and increase in β carotene content in F_2 as compared to their respective crosses in F_1 generation, respectively. Bhutani (1981) observed accumulation of favorable additive genes for carotenoids content. In the present study five crosses exhibited increase in β carotene content in F_2generation. Considering *per se* performance in F_1 and F_2 and ID altogether the cross Ec 490190x Arka Vikas appears to be the most suitable for exploiting high β carotene content in the present study.

Potassium content

Potassium is of vital importance to the functioning of the human body. Being an electrolyte, potassium is not stored in the body. Its losses increase by vomiting, diarrhea or extreme sweating. The RDA range set for potassium is in between 1875 to 5625 mg daily for adult was planned to result in Na:K ratio of 1:1 on molar basis with the objective of decreasing risk of hyper tension (Delvin, 2003). The estimates of BH and SH were low to moderate magnitude (Table 3). However, as in the case of protein and β carotene content investigated under present study, K content also had negative BH estimates. This could be due to inability of plants to assimilate the potassium needed by fruits during rapid period of accumulation (Maynard *et al.* 1980). The cross H 24 x Arka Vikasand Ec 177371 x Ec 398704 recorded positive estimates of heterobeltiosis and standard heterosis, respectively. This result is in agreement with Das *et al.* (1984). Three crosses *viz.,* GT 1 x Pusa Ruby, Pusa Ruby x Ec 163599 and ArkaVikasx Ec

398704 recorded higher amount of K content in F_2revealing accumulation of favourable gene among the parents involved in these cross combinations. Considering *per se* performance in F_1 and F_2, heterosis and inbreeding depression altogether, two crosses *viz.,* Ec 490190x Ec177371 and Pusa Ruby xEc177371 were better for high potassium content, hence, daily consumption of two to three fruits of these crosses would fulfill the recommended daily allowances of an adult thereby reducing the risk of hyper tension as well as can avoid muscle weakness, abdominal distension, cardiac abnormalities, respiratory failure, etc (Delvin, 2003).

Lycopene content

Heterosis estimates for lycopene content, were moderate to high magnitude in both directions (Table 2). Among 17 positively significant crosses, the cross GT 1 x H 24recorded high estimates of BH and higher estimates of SH, hence, preferred for high lycopene content over check variety Junagadh Ruby. Inbreeding depression in negative and positive direction was observed among 15 and 13 crosses, respectively. The crosses GT 1 x H 24, Pusa Ruby x Ec 398704, GT 1 x Pusa Ruby, and Arka Vikasx Ec 177371 that displayed significant positive heterosis in F_1 were also heterotic in F_2 generation. Hence, it is concluded that heterosis observed in F_1 also persist in F_2 generation for lycopene content. Earlier Bhutani (1981) also observed significant differences between F_1 and F_2 generation tomato crosses. Since *per se* performance, heterosis and inbreeding depression estimates were high for cross GT 1 x H 24, hence, preferred over others when high lycopene content is desired to combat free radicals that damage living tissue progressively (Khan *et al.* 2004).

The comparison of three crosses with high heterobeltiosis for fruit nutrition with other related attributing traits (Table 3) revealed that manifestation of heterosis for fruit yield and nutritional traits by cross GT 1 x H 24, also showed heterotic effects for nutritional traits. Hence it is suggested that this cross may be advanced and exploited hybrid vigour in future breeding programme for improving better fruit yield with enriched nutritional quality in tomato. Improvement in a complex attribute like fruit yield may be convenient if breeding programme will be made through attributing agro economical characters. The crosses that showed higher estimates of heterosis in general also showed high inbreeding depression.

Table 3: Comparative studies of top three heterobeltiotic crosses for fruit nutritional traits in 8 x 8 diallel set of tomato

Name of Cross	Percent heterosis over better parent (heterobeltiosis)								
	TSS (^{o}Brix)	Fruit acidity (%)	Carbohydrate (%)	Protein (%)	Ascorbic acid (mg 100 g^{-1})	Beta carotene (mg 100 g^{-1})	Potassium (mg 100 g^{-1})	Lycopene (mg 100 g^{-1})	Fruit yield (Kg $plant^{-1}$)
GT 1 x H 24	7.8	13.6	3.54	-11	3.54	NS -11	NS 3.68	55.2	98.67
Pusa Ruby x Arka Vikas	-18	-20	-1.5	-13	-1.5	NS -13	-38	16.87	88
Pusa Ruby x Ec 163599	3.5	-21	12.42	-25.67	12.42	NS -25.67	-33	NS 7.04	67

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