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Development of indeterminate tomato hybrids suitable for growing in mid-hills of Himachal Pradesh during summer and rainy seasons

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Abstract
Tomato (*Solanum lycopersicum* L.) is a member of family Solanaceae. In this study, heterosis for fruit yield, fruit transportability, nutritional quality and disease tolerance traits was studied in 15 hybrids developed from 6 diverse pure lines of indeterminate tomato crossed by following half-diallel mating scheme. The clear cut motive of this study was to develop indeterminate tomato hybrids suitable for growing in mid-hills of Himachal Pradesh to meet the demands of distant markets of North India during their off-season. Heterobeltiosis and standard heterosis for fruit yield traits, pericarp thickness, nutritional quality and disease tolerance traits were recorded significantly positive in three cross combinations *viz.* Solan Lalima x EC-1055, Solan Lalima x EC-1057 and Solan Lalima x EC-1058. Solan Lalima, EC-1055 and EC-1057 were found to be good general combiners. Predominance of dominant gene action was observed for traits included in this study. On the basis of this study, above mentioned three cross combinations can be recommended for evaluation at multi-locations and further commercialized in regions with off-season production potential.

Keywords: Diallel, indeterminate, traits, heterosis, gene action

Introduction

Tomato, *Solanum lycopersicum* L. (2n = 2x = 24), belongs to the large and diverse family Solanaceae which includes more than 3,000 species (Knapp, 2002) [16]. Although, the ancestral forms of tomato grew in the Peru-Ecuador area, the first domestication reported to have occurred in Mexico (Sims, 1980; Harvey *et al*., 2002) [21, 8]. Tomatoes are one of the most widely eaten vegetables in the world. India is the second largest producer of tomato after China with an annual production of 18.73 million tonnes from an area of 0.88 million ha and 21.2 tonnes/ha productivity. In Himachal Pradesh it is grown over an area of 10.37 thousand ha with an annual production of 430.79 thousand tonnes and a productivity of 41.54 tonnes/ha (Anonymous, 2015) [2].

In India, its fruits are used in a variety of ways but mostly eaten raw or in cooked form. Tomatoes are good source of potassium, vitamin C, folic acid and lycopene (antioxidant). It also contains vitamin E, vitamin K and flavonoids (Jones *et al.*, 1991) [11]. It has a low-calorie content of around 20 kcal/100 g of fruit and therefore, it is universally treated as protective food. It is grown as autumn-winter, winter and spring-summer crop in many parts of India but owing to high temperature and rains, tomato cannot be grown commercially in the North Indian plains from May to September. Mid-hills of Himachal Pradesh are leading supplier of fresh market tomatoes to the Northern markets of country during rainy and autumn season fetching lucrative off-season returns to the growers. Since, these markets are located far away from Himachal Pradesh so there is urgent need to develop tomato cultivars with good transportability with very less or no damage to fruits.

Hybridization may be used as a means of generating variation for selection in a breeding program. It may also be done to create the end product of a breeding program. The discovery of the phenomenon of heterosis laid the foundation for hybrid seed technology. Phenotypic superiority of a hybrid over its parents with respect to traits such as plant vigour, reproductive success, yield, quality and resistance to biotic and abiotic stresses is the results of heterosis. The commercial use of hybrids is restricted to those crops in which the amount of heterosis is sufficient to justify the extra cost required to produce hybrid seed. Though tomato is a self-pollinated crop, the unusual high heterosis observed in it has been attributed to the fact that, originally tomato was a highly out crossing genus which has later evolved into a self-pollinated one (Rick, 1969) [19]. Heterosis breeding is a tool for genetic improvement ever since the phenomenon of hybrid vigour was noticed by Hedrick and Booth (1907) [10] in tomato.

In the beginning, tomato hybrids had to compete only with the usual open pollinated cultivars. This was easily achieved by the breeders. That is why large number of commercial hybrids has been developed in this crop. The problem, however, became more complicated later on, when the new hybrids started to compete with other hybrids not from local but also multinational private companies. The breeders of these companies started utilizing parental lines from distant geographic regions or lines derived through interspecific hybridization with the conception that the heterosis effect increases with the increase of diversity between parents. Large numbers of tomato hybrids are under cultivation in the country but market is mostly dominated by hybrids of multinational companies and to a lesser extent by public sector hybrids/varieties.

The performance of any hybrid is directly linked to combining ability of its parental lines. The general combining ability of a tomato inbred is indicated by its phenotypic performance in a number of cross combination *i.e*., high yielding inbred lines generally are superior parents for yield. The fullest and most precise assessment of combining ability is given by the method of diallel crossing (Kalloo *et al.*, 1974) [15]. The design and efficiency of breeding programs depends on the relative importance of different types of gene action. Therefore, manipulating heterosis in breeding programs requires knowledge of its quantitative genetic basis. The information on gene action involved in the expression of both qualitative and quantitative traits may be approached by predictability ratio analysis that helps us in formulating an effective breeding strategy.

To meet the ever-increasing demand of North Indian markets during off-season of tomato, there is urgent need to develop new indeterminate hybrids for farmers of Himachal Pradesh with higher production level, good transportability and resistant to biotic and abiotic stresses.

Materials and Methods

This study was conducted during *Kharif* 2014-15 and 2015-16 at research farm of the Department of Vegetable Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh). It is located at an altitude of 1276 meters amsl, longitude of $77^0\ 11'\ 30''$ E and latitude of $30^0\ 52'\ 30''$ N. There were six tomato inbred lines in the experimental material *viz.*, Solan Lalima, UHF-55, EC-2798, EC-1055, EC-1057 and EC-1058 were crossed in diallel (excluding reciprocal) fashion to develop 15 cross combinations. Six parents, fifteen F_1 and standard check (Naveen 2000 +) were evaluated using Randomized Complete Block Design (RCBD) with three replications. The seedlings were transplanted at a spacing of 90 cm x 30 cm. Standard cultural practices were followed. The observations were recorded on parameters *viz.*, days to first harvest, fruit clusters per plant, number of fruits per plant, harvest duration (days), fruit yield (kg/plant), pericarp thickness (mm), lycopene content (mg/100g), ascorbic acid content (mg/100g), buck eye rot incidence (%) and alternaria leaf blight severity (%). The analysis of variance (ANOVA) was set as explained by Gomez and Gomez (1983) [4] and heterosis over better parent and standard check Naveen 2000 + were worked out using techniques of Allard (1960) [1]. Griffing (1956) [6] and Hayman (1957) [9] approaches were followed to draw valid conclusions from diallel analysis.

Results and Discussion

The significant variations were observed among all parents and hybrid combinations for all the horticultural traits under this study (Table-1). The genotypes, EC-1055 (54.00 days) and EC-1057 (57days) among parents while Solan Lalima x EC-1057 (57.33) and Solan Lalima x EC-1058 (58.00) and Solan Lalima x EC-1055 (59.33 days) among cross combinations were found superior for earliness. Heterosis studies revealed significant desirable heterosis for earliness (Table-2). Out of fifteen cross combinations four cross combinations, Solan Lalima X EC-1057, Solan Lalima X EC-1058, Solan Lalima X EC-1055 and EC-1057 X EC-1058 were significantly earlier in flowering to standard check. Rana and Vidyasagar (2005) [18] have also reported hybrids taking lesser time to first fruit harvest as compared to the respective better parents which is considered desirable parameter for fetching premium prices from early harvests in tomato markets of the North India. GCA effects for days to first harvest revealed that EC-1055, EC-1057 and Solan Lalima were found to be best general combiners due to their significant negative GCA effects (Table-3). Solan Lalima x EC-1058, Solan Lalima x EC-1057 and EC-2798 x EC-1055 showed significant negative SCA effects (Table-4). Variance due to SCA was higher than that of GCA and predictability ratio was also less than 1 for this trait thus indicating the role of non-additive gene action for earliness (Table-5).

The ultimate goal of any breeding programme is to achieve maximization of marketable yield. Yield is a complex trait and is dependent on many component traits. This is also the key factor in adoption or rejection of a variety or hybrid by the farmer. Solan Lalima x EC-1055 had maximum fruit clusters per plant (9.28), which was found statistically at par with Solan Lalima x EC-1057 (9.07) and Solan Lalima x EC-1058 (9.03). Similar trend was noticed by Sajjan (2001), Kulkarni (2003) and Duhan *et al*. (2005a). Only one cross, Solan Lalima x EC-1055 (9.0%) showed significant positive heterosis over standard check Naveen 2000 +. These results are in line with Joshi and Thakur (2003) [12] and Sharma and Thakur (2008) [20]. Amongst the crosses, number of fruits per plant varied from 15.30 (EC-1055 x EC-1057) to 46.94 (Solan Lalima x EC-1055), later one statistically at par with 45.37 (Solan Lalima x EC-1057). Two cross combinations *viz.*, Solan Lalima x EC-1055 (17.70%) and Solan Lalima x EC-1057 (13.77%) showed significant positive increase over Naveen 2000 + for this trait. Positive heterosis over better parent and standard check for this trait has also been reported by Kumari *et al*. (2010) [17], Singh and Sastry (2011) [22] and Singh *et al.* (2012) [23]. For yield and component traits Solan Lalima was good general combiner and expressed significant positive GCA effects among all these traits except for fruit size. Solan Lalima and UHF-55 were good general combiners for fruit clusters per plant, harvest duration and fruit yield. Among crosses Solan Lalima x EC-1055, Solan Lalima x EC-1057 and Solan Lalima x EC-1058 were good specific combiners for fruit clusters per plant, number of fruits per plant, harvest duration and fruit yield traits. Non additive gene action was predominant over the expression of these traits as indicated by <1 predictability ratio. Out of fifteen cross combinations, three crosses showed significant positive heterosis over standard check Naveen 2000+ for fruit yield (kg/plant), the highest being in Solan Lalima x EC-1055 (15.81%) followed by Solan Lalima x EC-1057 (11.76%) and Solan Lalima x EC-1058 (8.46%). Positive heterosis for fruit yield was reported earlier by Gul *et al.* (2010) [7] and Singh *et al*. (2012) [23].

Longer harvest duration ensures the continuous supply of produce and good price of tomato for over a longer period. It also keeps a balance between the demand and supply, thereby in avoiding glut in the market and fall in prices. Amongst F_1s minimum harvest duration (days) were recorded in EC-1057 x EC-1058 (40.49) while maximum in Solan Lalima x EC-1055 (91.96) followed by Solan Lalima x EC-1057 (85.28). Joshi *et al.* (2005) [14] could not record any increase in harvest duration in the hybrids studied by them in comparison to the standard check.

Fruits having high pericarp thickness can withstand shipping and remain firm for more number of days as compared to thin fleshed fruits. Maximum pericarp thickness was recorded in Solan Lalima x EC-1055 (5.45) which was statistically at par with Solan Lalima x EC-1057 (5.42 mm) and Solan Lalima x EC-1058 (5.38 mm). Three crosses *viz.*, Solan Lalima x EC-1055 (5.62%), Solan Lalima x EC-1057 (5.04%) and Solan Lalima x EC-1058 (4.26%) showed significant increase over the standard check for this trait. Positive heterosis over better parent and standard check for pericarp thickness has also been reported by Sharma and Thakur (2008) [20] and Graca *et al.* (2015) [5]. Positive heterosis for fruit firmness becomes especially important when resistance during bulk transportation is an issue, independently of the tomato end use. In the present context, fruit firmness is indisputably relevant, since production zones are often remote in relation to trade centers. Out of fifteen cross combinations, seven showed significant positive increase over standard check and highest increase was observed with Solan Lalima. Three crosses showed significant increase over standard check *viz.*, Solan Lalima x EC-1055, Solan Lalima x EC-1057 and Solan Lalima x EC-1058 for shelf life trait. Garg & Cheema (2011) and Graca *et al.* (2015) [5] also reported positive heterosis in one and more cross combinations for fruit firmness in tomato.

For diseases significant negative heterosis was observed for Solan Lalima x EC-1055, Solan Lalima x EC-1057 and Solan Lalima x EC-1058. Negative heterosis for this trait in the crosses has also been reported by Joshi *et al*. (2004) [13]. Solan Lalima, EC-1055 and EC-1057 were good general combiners for buck eye rot incidence and alternaria leaf blight severity. Variance ratio was recorded to be less than one for alternaria leaf blight severity indicated non additive gene control while variance ratio equal to 1 was recorded in buck eye rot incidence indicating the importance of both additive as well as non-additive genes governing this parameter.

Table 1: Mean performance of parents and crosses and check for different horticultural traits in tomato

Parents/crosses	DFH	FCPP	NFPP	HD	FY	PT	LC	AAC	BER	ALB
Solan Lalima	67.33	8.75	40.25	71.55	2.64	3.66	5.06	32.03	10.71	23.03
UHF-55	70.00	7.59	26.02	64.93	2.45	4.23	5.28	29.68	16.83	31.60
EC-2798	69.00	7.25	33.36	67.33	2.05	3.66	5.65	25.75	19.29	26.09
EC-1055	54.00	4.60	17.00	41.40	1.55	4.94	3.70	21.42	25.01	22.67
EC-1057	57.00	4.69	17.33	42.47	1.34	4.41	2.28	24.71	27.51	23.73
EC-1058	61.00	4.37	15.16	38.27	1.06	4.55	2.55	24.19	26.08	23.76
Solan Lalima X UHF-55	71.67	7.63	24.42	62.58	2.56	3.48	5.32	34.10	13.99	24.64
Solan Lalima X EC-2798	71.33	8.27	28.94	70.41	2.53	3.25	5.00	31.62	15.70	25.61
Solan Lalima X EC-1055	59.33	9.28	46.94	91.96	3.15	5.45	6.52	36.18	7.08	15.35
Solan Lalima X EC-1057	57.33	9.07	45.37	85.28	3.04	5.42	5.47	34.44	8.73	15.90
Solan Lalima X EC-1058	58.00	9.03	42.38	66.71	2.95	5.38	5.40	34.63	9.23	15.54
UHF-55 X EC-2798	73.67	7.48	24.94	64.70	2.44	4.20	4.52	29.22	16.28	24.03
UHF-55 X EC-1055	65.00	7.94	31.00	67.96	2.94	4.15	5.44	32.54	19.38	24.89
UHF-55 X EC-1057	66.67	7.89	30.79	67.99	2.93	4.32	5.71	31.33	19.20	23.32
UHF-55 X EC-1058	68.33	7.21	22.41	56.61	2.65	4.37	4.80	29.36	20.42	26.89
EC-2798 X EC-1055	64.00	7.64	37.41	70.50	2.04	3.18	4.89	30.66	20.34	25.85
EC-2798 X EC-1057	79.67	6.05	16.19	66.33	1.98	4.12	3.40	24.77	19.33	26.77
EC-2798 X EC-1058	83.00	5.30	16.59	60.27	1.76	2.69	3.10	24.35	26.48	25.42
EC-1055 X EC-1057	64.67	5.20	15.30	41.40	1.47	4.80	3.84	21.73	27.90	23.15
EC-1055 X EC-1058	68.33	5.48	17.63	40.97	1.34	5.23	3.21	26.72	25.75	25.53
EC-1057 X EC-1058	60.00	5.32	16.66	40.49	1.13	4.88	3.61	24.25	26.28	24.77
Naveen 2000+ (Standard check)	64.00	8.51	39.88	73.48	2.72	5.16	5.19	30.70	13.52	23.88
Population mean	66.06	7.02	27.54	61.53	2.22	4.34	4.54	28.84	25.59	23.75
SE(m)±	1.14	0.24	1.82	1.86	0.03	0.04	0.11	1.07	0.44	0.54
$CD_{(0.05)}$	2.28	0.48	3.65	3.72	0.05	0.09	0.23	2.14	0.89	1.08

Where,

DFH=days to first harvest, PH=plant height (cm), FCPP= fruit clusters per plant, NFPC=number of fruits per cluster, NFPP=number of fruits per plant, FS=fruit size (cm^2), AFW=average fruit weight (g), HD=harvest duration (days), FY=Fruit yield (kg/plant), PT=pericarp thickness (mm), FF=fruit firmness ($g/0.503\ cm^2$), TSS=total soluble solids (°Brix), LC=lycopene content (mg/100g), AAC=ascorbic acid (mg/100g), SL=shelf life (days), BER=buck eye rot incidence (%), ALB=alternaria leaf blight severity (%), SLB=septoria leaf blight severity (%) and FBI=fruit borer infestation (%)

Table 2: Heterobeltiotic effects and standard heterosis for important horticultural traits in tomato

Crosses	DFH		FCPP		NFPP		HD		FY		PT		LC		AAC		BER		ALB	
	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH	HB	SH
Solan Lalima X UHF-55	6.45*	11.98*	-12.80*	-10.34*	-39.33*	-38.77*	-12.54*	-14.83*	-3.03	-5.88	-17.73*	-32.56*	0.83	2.50	6.46	11.07*	30.62*	3.50	6.97*	3.16
Solan Lalima X EC-2798	5.94*	11.45*	-5.49	-2.82	-28.10*	-27.43*	-1.59	-4.18	-4.17	-6.99	-11.20*	-37.02*	-11.52*	-3.66	-1.28	3.00	46.58*	16.15*	11.19*	7.23*
Solan Lalima X EC-1055	9.87*	-7.30*	6.06	9.05*	16.62*	17.70*	28.53*	25.15*	19.32*	15.81*	10.32*	5.62*	28.75*	25.63*	12.96*	17.85*	-33.88*	-47.61*	-32.27*	-35.72*
Solan Lalima X EC-1057	0.58	-10.42*	3.66	6.58	12.72*	13.77*	19.19*	16.06*	15.15*	11.76*	22.90*	5.04*	7.96*	5.34*	7.52*	12.18*	-18.50*	-35.42*	-30.97*	-33.44

Solan Lalima X EC-1058	-4.92*	-9.38*	3.20	6.11	5.29	6.27	-6.76	-9.21*	11.74*	8.46	18.24*	4.26*	6.69*	4.10	8.12*	12.80*	-13.81*	-31.71*	-32.55*	-34.96*
UHF-55 X EC-2798	6.77*	15.11*	-1.45	-12.10*	-25.24*	-37.46*	-3.91	-11.95*	-0.41	-10.29*	-0.71	-18.60*	-20.01*	-12.91*	-1.55	-4.82	-3.23	20.44*	-7.91*	0.61
UHF-55 X EC-1055	20.37*	1.56	4.61	-6.70	19.14*	-22.27*	4.67	-7.51	20.00*	8.09	-15.99*	-19.57*	3.11	4.82*	9.64*	5.99	15.19*	43.37*	9.81*	4.22
UHF-55 X EC-1057	16.96*	4.17*	3.95	-7.29	18.33*	-22.79*	4.71	-7.47	19.59*	7.72	-2.04	-16.28*	8.17*	9.96*	5.56*	2.05	14.08*	41.99*	-1.75	-2.38
UHF-55 X EC-1058	12.02*	6.77*	-5.01	-15.28*	-13.87	-43.81*	-12.81*	-22.96*	8.16	-2.57	-3.96*	-15.31*	-9.08*	-7.57*	-1.08	-4.36	21.33*	51.01*	13.18*	12.59*
EC-2798 X EC-1055	18.52*	0.00	5.38	-10.22*	12.14	-6.19	4.71	-4.06	-0.49	-25.00*	-35.63*	-38.37*	-13.41*	-5.72*	19.07*	-0.13	5.44*	50.44*	14.03*	8.24*
EC-2798 X EC-1057	39.77*	24.48*	-16.55*	-28.91*	-51.47*	-59.40*	-1.49	-9.73*	-3.41	-27.21*	-6.58*	-20.16*	-39.89*	-34.55*	-3.81	-19.32*	0.21	42.97*	12.81*	12.09*
EC-2798 X EC-1058	36.07*	29.69*	-26.90*	-37.72*	-50.27*	-58.40*	-10.49*	-17.98*	-14.15*	-35.29*	-40.88*	-47.87*	-45.07*	-40.19*	-5.44	-20.68*	37.27*	95.86*	7.00*	6.44*
EC-1055 X EC-1057	19.76*	1.05	10.87	-38.90*	-11.71	-61.63*	-2.52	-43.66*	-5.16	-45.96*	-2.83*	-6.98*	3.78	-26.01*	-12.06*	-29.22*	11.54*	106.36*	2.11	-3.08
EC-1055 X EC-1058	26.54*	6.77*	19.13*	-35.61*	3.71	-55.79*	-1.04	-44.24*	-13.55	-50.74*	5.87	1.36	-13.38*	-38.25*	10.46*	-12.96*	2.96*	90.48*	12.59*	6.87*
EC-1057 X EC-1058	5.26*	-6.25*	13.43	-37.49*	-3.87	-58.22*	-4.66	-44.90*	-15.67	-58.46*	7.25*	-5.43*	41.32*	-30.48*	-1.86	-21.01*	0.76	94.38*	4.36	3.69

*significant at 5% level
Where,
HB=heterobeltiosis and SH=standard heterosis

Table 3: Estimates of general combining ability of parents for important horticultural traits in tomato.

Parents	DFH	FCPP	NFPP	HD	FY	PT	LC	AAC	BER	ALB
Solan Lalima	-1.81*	1.51*	9.98*	11.67*	0.52*	0.02*	0.78*	4.23*	-7.21*	-2.88*
UHF-55	3.69*	0.58*	-0.39	2.87*	0.39*	-0.14*	0.59*	1.84*	-1.37*	2.60*
EC-2798	5.36*	0.07	0.26	5.02*	-0.06*	-0.67*	0.08*	-1.14*	0.36*	1.71*
EC-1055	-4.68*	-0.49*	-0.80	-3.89*	-0.16*	0.32*	-0.04	-1.32*	2.08*	-0.76*
EC-1057	-3.06*	-0.72*	-3.72*	-5.03*	-0.26*	0.28*	-0.63*	-1.91*	2.83*	-0.60*
EC-1058	0.49	-0.95*	-5.34*	-10.64*	-0.42*	0.19*	-0.79*	-1.69*	3.31*	-0.06*
SE(gi)	0.268	0.06	0.417	0.653	0.025	0.01	0.026	0.25	0.132	0.122
SE (gi-gj)	0.414	0.09	0.646	1.012	0.038	0.016	0.04	0.39	0.204	0.188
CD (gi)	0.56	0.12	0.87	1.36	0.05	0.02	0.05	0.52	0.27	0.25
CD (gi-gj)	0.86	0.18	1.34	2.10	0.08	0.03	0.09	0.80	0.42	0.39

Table 4: Estimates of specific combining ability of cross combinations for important horticultural traits in tomato

Crosses	DFH	FCPP	HD	FY	PT	LC	AAC	BER	ALB
SL x UHF-55	3.10*	-1.42	-12.92*	-0.54*	-0.70*	-0.57*	-0.71	3.447*	1.18*
SL x EC-2798	1.10	-0.27	-7.24*	-0.12	-0.40*	-0.37*	-0.22	3.433*	3.05*
SL x EC-1055	-0.86	1.30*	23.23*	0.60*	0.80*	1.26*	4.53*	-6.91*	-4.74*
SL x EC-1057	-4.49*	1.33*	17.69*	0.59*	0.81*	0.80*	3.38*	-6.01*	-4.36*
SL x EC-1058	-7.36*	1.52*	4.72*	0.67*	0.86*	0.90*	3.35*	-5.99*	-5.26*
UHF x EC-2798	-2.07*	-0.12	-4.15*	-0.07	0.71*	-0.67*	-0.23	-1.83*	-4.02*
UHF-55 x EC-1055	-0.70	0.89*	8.01*	0.52*	-0.33*	0.37*	3.28*	-0.45	-0.69
UHF-55 x EC-1057	-0.66	1.08*	9.20*	0.62*	-0.12*	1.23*	2.66*	-1.39*	-2.42*
UHF-55 x EC-1058	8.47*	0.63*	3.41	0.50*	0.02	0.48*	0.47	-0.65	0.62
EC-2798 x EC-1055	-3.36*	1.11*	8.42*	0.07	-0.77*	0.34*	4.37*	-1.22*	1.16*
EC-2798 x EC-1057	10.68*	-0.26	5.39*	0.11	0.21*	-0.57*	-0.93	-2.98*	1.92*
EC-2798 x EC-1058	10.47*	-0.78*	4.93*	0.05	-1.13*	-0.69*	-1.57*	3.69*	0.04
EC-1055 x EC-1057	5.72*	-0.54*	-10.64*	-0.29*	-0.10*	-0.01	-3.78*	3.87*	0.77
EC-1055 x EC-1058	5.85*	-0.04	-5.46*	-0.27*	0.41*	-0.48*	0.98	1.24*	2.61*
EC-1057 x EC-1058	-4.11*	0.04	-4.80*	-0.37*	0.11*	0.51*	-0.90	1.02*	1.69*
SE (sij)	0.735	0.15	1.794	0.068	0.028	0.071	0.69	0.36	0.33
SE (sij-sik)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
SE (sij-skl)	1.02	0.21	2.48	0.09	0.04	0.10	0.95	0.5	0.46
CD (sij)	1.53	0.32	3.73	0.14	0.06	0.15	1.43	0.75	0.69
CD (sij-sik)	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
CD (sij-skl)	2.11	0.44	5.16	0.19	0.08	0.20	1.97	1.04	0.96

Table 5: Estimates of genetic components of variance for important horticultural traits in tomato

Character	σ^2 gca	σ^2 sca	$\sigma^2 g$	$\sigma^2 s$	$\sigma^2 g/\sigma^2 s$ (Variance Ratio)
Days to first harvest	123.41	43.67	15.17	41.61	0.36
Fruit clusters per plant	6.86	1.15	0.85	1.06	0.80
Number of fruits per plant	228.40	74.08	27.92	69.07	0.34
Harvest duration (days)	517.14	130.16	63.97	124.80	0.51
Fruit yield (Kg/plant & q/ha)	1.12	0.24	0.14	0.24	0.59
Pericarp thickness (mm)	351.88	53.58	43.50	49.69	0.88
Fruit firmness (lb/cm^2)	108099.60	21903.01	13487.62	21704.37	0.62
Lycopene content (mg/100g)	0.15	0.14	0.02	0.13	0.15
Ascorbic acid content (mg/100g)	21.62	20.38	2.48	18.57	0.13
Buck eye rot incidence (%)	123.60	15.87	15.39	15.37	0.99
Alternaria leaf blight severity (%)	30.30	10.23	3.73	9.81	0.38
Septoria leaf blight severity (%)	22.17	8.26	2.67	7.42	0.36

Conclusion

On the basis of present studies it is concluded that three cross combinations *viz.*, Solan Lalima x EC-1055, Solan Lalima x EC-1057 and Solan Lalima x EC-1058 were possessing significant positive heterosis for almost all the traits including yield over standard check and also has showed their worth in combining ability studies. Therefore, may be recommended for commercial cultivation after multi location testing or can be further utilized to get transgressive segregants with a combination of traits in segregating generations.

References

1. Allard RW. Principles of Plant Breeding. John Wiley and Sons, New York, 1960, 485.
2. Anonymous. Handbook of Indian Horticulture Database, NHB, Gurgaon. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, 2015, 48.
3. Garg N, Cheema DS. Assessment of fruit quality attributes of tomato hybrids involving ripening mutants under high temperature conditions. Scientia Horticulturae. 2011; 131:29-38.
4. Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research. 2nd Edition, John Wiley and Sons, New York, 1983.
5. Graca AJP, Junior ATA, Rodrigues R, Goncalves LSA, Sudre CP, Vivas M *et al*. Heterosis and combining ability of dual-purpose tomato hybrids developed to meet family farmers' needs in Brazil and Mozambique. Horticultura Brasileira. 2015; 33:339-344.
6. Griffing B. Concept of general and specific combining ability in relation to diallel crossing system. Australian Journal of Biological Sciences. 1956; 9:463-493.
7. Gul R, Rahman HU, Khalil IH, Shah SMA, Ghafoor A. Heterosis for flower and fruit traits in tomato (*Lycopersicon esculentum* Mill.). African Journal of Biotechnology. 2010; 9(27):4144-4151.
8. Harvey M, Quilley S, Beynon H. Exploring the Tomato. Transformations of Nature, Society and Economy. Edgar Publishing, Cheltenham, UK, 2002, 304.
9. Hayman BI. Interaction, heterosis and diallel crosses. Genetics. 1957; 42:336-355.
10. Hedrick UP, Booth N. Mendelian characters in tomato. Proceedings of American Society of Horticultural Sciences. 1907; 5:19-23.
11. Jones JB, Jones JP. Compendium of Tomato Diseases. R.E. Stall, and T.A. Zitter. (Eds.) APS Press, Saint Paul, Minnesota, USA, 1991.
12. Joshi A, Thakur MC. Exploitation of heterosis for yield contributing traits in tomato (*Lycopersicon esculentum* Mill.). Indian Journal of Horticulture. 2003; 55(1):64-68.
13. Joshi A, Gupta SK, Kohli UK. Resistance to Septoria leaf spot (*Septoria lycopersici*) and buckeye fruit rot (*Phytophthora nicotianae var. parasitica*) of tomato (*Lycopersicon esculentum*). Indian Journal of Horticulture. 2004; 74(4):194-199.
14. Joshi A, Thakur MC, Kohli UK. Heterosis and combining ability for shelf life, whole fruit firmness and related traits in tomato. Indian Journal of Horticulture. 2005; 61(1):33-36.
15. Kalloo G, Singh RK, Bhutani RD. Combining ability studies in tomato (*Lycopersicon esculentum* Mill.). Theoretical and Applied Genetics. 1974; 44:358-363.
16. Knapp S. Assessing patterns of plant endemism in Neotropical Uplands. The Botanical Review. 2002; 68:22-37.
17. Kumari N, Srivastava JP, Singh B, Deokaran. Heterotic expression for yield and its components in tomato (*Lycopersicon esculentum* Mill). Annals of Horticulture. 2010; 3(1):98-101.
18. Rana, Vidyasagar. Exploitation of heterosis for yield and certain quality traits in tomato (*Lycopersicon esculentum* Mill.). Udyanika, Journal of Horticultural Sciences. 2005; 11(2):67-70.
19. Rick CM. Origin of cultivated tomato, current status and the problem. International Botanical Congress, 1969, 180.
20. Sharma D, Thakur MC. Evaluation of diallel progenies for yield and its contributing Traits in tomato under mid hill conditions. Indian Journal of Horticultural Sciences. 2008; 30(3-4):236-238.
21. Sims WL. History of tomato production for industry around the world. Acta Horticulturae. 1980; 100:25-26.
22. Singh J, Sastry EVD. Heterosis and stress susceptibility index for fruit yield and contributing traits in tomato (*Lycopersicon esculentum*). Indian Journal of Agricultural Sciences. 2011; 81(10):957-966.
23. Singh NB, Wani SH, Haribhushan A, Nongthombam R. Heterosis studies for yield and its components in tomato (*Solanum lycopersicum* L.) under valley conditions of Manipur. Vegetos. 2012; 25(2):257-265.