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Heterosis expression, interrelationship, direct and indirect effects of component characters on yield in intervarietal crosses of eggplant

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Heterosis has been amply exploited in developing hybrids in brinjal. In India, only 17.8% area of brinjal cultivation is under hybrid seed due to lack of appropriate hybrids for specific area and purpose. In the present investigation, 14 parents were selected on the basis of divergence and mated in line (L) × tester (T) design hybrids and parents were raised to measure heterosis for different yield attributes. 40 hybrids resulting from a L × T mating design comprised of 10 lines (female) and 4 testers (males) were studied to determine the magnitude of heterosis and genotypic correlation between yield and yield characters. Expression of superiority over the commercial check occurred in 7 crosses, which ranged from -56.36 (L_3 × T_4) to 34.07% (L_7 × T_2). The hybrid (L_7 × T_2) had good heterosis values for growth and yield and is recommended as the most promising combination for developing high yielding hybrid eggplant varieties. Most crosses involving T_2 as tester parent had significant positive heterosis over the mid-parent and standard variety. There were strong correlations between fruit yield and numbers of branches per plant, average fruit weight and number of fruit per plant. Path analysis indicated that plant height, number of branches per plant, fruit length, fruit pedicel length, number of fruit per plant, average fruit weight and little leaf incidence had direct and positive effects on yield per plant, but negative and direct effects occurred for days to first flowering, fruit circumference, calyx length, shoot borer infestation, fruit borer infestation, ascorbic acid content and total phenol content. Simple selection would be effective for improvement of fruit yield.

Key words: *Solanum melongena,* association analysis, hybrid vigour.

INTRODUCTION

Brinjal (*Solanum melongena* L.), also known as eggplant and an important vegetable crop of India. It is widely cultivated in both temperate and tropical regions of the globe mainly for its immature fruits. In Tamilnadu (India), the productivity of brinjal is less as compared to national average, owing to use of low yielding cultivars grown for

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local preferences and their susceptibility to pests and diseases (Nalini, 2007). The present production is not proportionate with the demand. So, brinjal deserves a deep deliberation for improvement. It should be highly pragmatic by the fact that, India being the centre of origin and diversity of brinjal, it should pave the way for bringing about a kind of plant type, which could enhance its quality and productivity without sacrificing the consumer needs (Shafeeq et al., 2007). Quality and productivity of eggplant can be improved through heterosis breeding (Kakikazi, 1931). The estimation of heterosis for yield and its component characters would be useful to judge the best hybrid combination for exploitation of superior hybrids. Genotypic correlations exist between yield and yield attributing characters are important in breeding. Yield is the end product of many correlated characters. Selection for yield would be more effective when it is based on component characters which are positively correlated. When more number of variables is considered in correlation, the association becomes more complex. Use of path coefficient analysis makes clear direct and indirect associations and identifies the most reliable yield contributing characters (Daliya and Wilson, 2002). The study was under taken to study the extent of heterosis in different crosses and their utilization in future crop improvement.

MATERIALS AND METHODS

The experiment was conducted during June to October (*kharif)* 2010 to 2011 at College Orchard, Agricultural College and Research Institute, Madurai, India, situated at 9°5 N latitude and 78°5 E longitudes at 147 m above MSL. Ten lines were crossed with 4 testers through Line × Tester mating design to derive 40 F_1 hybrids (Table 1). The hybrids and 14 parents were established in a sandy loam soil and arranged in a Randomized Complete Block Design with three replications. Three ploughings were done with cultivator to make the soil fine tilth. Thirty (30)-day-old seedlings raised in the nursery beds were transplanted on ridges with a spacing of 60 × 60 cm. 30 plants were maintained for each hybrid and parent in each replication. Cultural practices were followed uniformly for all hybrids and (TNAU Crop Production Guide, 2005). Observations were recorded from 5 randomly selected plants in each replication. The data recorded for the traits plant height, days to first flowering, number of branches per plant, fruit length, fruit circumference, number of fruit per plant, average fruit weight and fruit yield per plant for estimating heterosis. Selections were made in F_1 hybrids based on fruit shape, color, size and fruit yield per plant. Superior hybrids were selected and selfed. Seed were collected from selfed fruit and stored for further breeding.

The magnitude of heterosis in hybrids was expressed as percent of increase or decrease of a character over mid-parent (d_i), better parent (d_{ii}) and standard hybrid (d_{iii}) and estimated following the formula of Fonseca and Patterson (1968). The significance of magnitude of the relative heterosis, heterobeltiosis and standard heterosis was tested with the formula suggested by Turner (1953). Correlation coefficients were computed using formulae of Johnson et al. (1955). Path coefficients were obtained following the method of Dewey and Lu (1959).

RESULTS AND DISCUSSION

The analysis of variance revealed that parents showed significant differences for all characters (Table 2). Variance due to lines was significant for all traits indicating existence of genetic variability for growth and yield attributes among lines (females) and testers (males). The interaction between lines × testers was also significant for all the growth and yield traits.

Average performance and magnitude of heterosis for different quantitative characters varied (Table 3). In parents, T_2 (66.90 cm) had the shortest plants and L_2 (98.83 cm) was tallest. The hybrid $L_1 \times T_4$ recorded tallest plants height, followed by $L_2 \times T_1$ with positive heterosis over mid, better and standard parents indicating over-dominance. Among the 40 hybrids, 15 had significant positive over the mid-parent for plant height. Three hybrids had significant positive heterosis and one hybrid had significant negative heterosis ($L_6 \times T_3$) over the better parent. Twenty-seven (27) of 40 hybrids had significant positive heterosis over standard variety and the extent of heterosis over the standard variety. Similar findings were reported by Preneetha (2002) and Thangamani (2003).

Earliness is considered an important character in any crop improvement programme, which is manifested in F_1 hybrids and preferred for commercial cultivation when high yield is coupled with earliness. The hybrid $L_8 \times T_1$ had the shortest period of days to first flower and $L_8 \times T_4$ had the longest period. For days to first flowering negative heterosis is desirable. Of 40 hybrids, 8 ($L_1 \times T_1$, $L_4 \times T_1$, $L_5 \times T_1$, $L_6 \times T_1$, $L_6 \times T_3$, $L_7 \times T_3$, $L_8 \times T_1$ and $L_{10} \times T_1$) had significant heterosis in the desirable direction over the mid-parent. Seventeen (17) hybrids had significant heterobeltiosis in the negative direction (desirable). As many as 29 hybrids had heterosis in the desirable direction over the standard variety; only 2 ($L_3 \times T_2$ and $L_8 \times T_4$) had significant positive heterosis over the standard variety.

Number of branches per plant influences yield. Of 40 crosses, the highest number of branches per plant was for $L_6 \times T_2$. Of 40 hybrids 21 had significant positive heterosis while three hybrids (L_2 x T_1 and $L_8 \times T_4$) exhibited significant negative heterosis. Seventeen hybrids had significant heterosis over the better parent, of which 10 had heterosis in the positive direction and 7 (L_2 x T_1, L_2 x T_3, L_4 x T_3, $L_8 \times T_4$, $L_{10} \times T_1$, L_{10} x T_3 and L_{10} x T_4) had heterosis in the negative direction. In 18 hybrids, there was significant heterosis in the negative direction, where-as three hybrids (L_5 x T_2, L_6 x T_2 and L_7 x T_2) had significant positive heterosis over standard variety. These results agree with findings of Preneetha (2002).

Fruit length is an important character to be considered while selecting eggplant for high yield. The longest fruit was in T_1 followed by L_8 and shortest fruit were in T_2. The hybrid L_6 x T_1 exhibited good performance and heterobeltiosis for fruit length. 21 hybrids had significant negative

Table 1. Features of parents used in study.

Name of local type	Flower bearing	Fruit bearing	Fruit shape	Fruit color	Calyx type	Calyx spininess	Source	Symbol
Lines								
Alavayal Local	Cluster	Cluster	Round	Light purple	Persistent	Non- spiny	Alavayal, Madurai D.t ,Tamil Nadu	L_1
Sedapatty Local (Green)	Cluster	Cluster	Oval	Purplish green	Persistent	Non- spiny	Sedapatty, Madurai D.t, Tamil Nadu	L_2
Kariapatty Local	Cluster	Cluster	Round	Green striped	Persistent	Non- spiny	Kariapatty, Virdhunagar D.t, Tamil Nadu	L_3
Alagarkovil Local	Cluster	Cluster	Round	Green striped	Persistent	Non- spiny	Alagarkovil, Madurai D.t, Tamil Nadu	L_4
Palamedu Local	Cluster	Cluster	Round	Light blue	Persistent	Non- spiny	Palamedu, Madurai D.t, Tamil Nadu	L_5
Melur Local	Cluster	Cluster	Round	Purple	Persistent	Non- spiny	Melur, Madurai D.t, Tamil Nadu	L_6
Keerikai Local	Cluster	Cluster	Oval	Purplish green	Persistent	Non- spiny	Sempatty, Dindigul D.t, Tamil Nadu	L_7
Nilakottai Local	Cluster	Cluster	Oblong	Green striped	Persistent	Non- spiny	Nilakottai, Dindigul D.t, Tamil Nadu	L_8
Singampunari Local	Cluster	Cluster	Round	Purplish green	Persistent	Non- spiny	Singampunari, Sivagangai D.t, Tamil Nadu	L_9
Sedapatty Local (Blue)	Cluster	Cluster	Round	Purple striped	Persistent	Non- spiny	Sedapatty, Madurai D.t, Tamil Nadu	L_{10}
Tester								
Annamalai	Cluster	Cluster	Long	Purple	Non persistent	Non- spiny	Vegetable Research Station, Palur, Tamil Nadu	T_1
KKM 1	Cluster	Cluster	Egg shaped	White	Persistent	Non- spiny	Agricultural College and Research Institute, Tuticorin, Tamil Nadu	T_2
Punjab Sadabahar	Cluster	Cluster	Long	Purple	Non persistent	Non- spiny	Tamil Nadu agricultural university, Coimbatore	T_3
EP 65	Cluster	Cluster	Oval	Dark purple	Non persistent	Non- spiny	Vegetable Research Station, Palur, Tamil Nadu	T_4

heterosis over the mid-parent.

A total of 27 hybrids had significant heterosis over the better parent in desirable direction (negative). Useful heterosis was exhibited by all 40 hybrids over the standard variety. The cross combination exceed-ing the superior parent is a valuable character in heterosis breeding (Patil et al., 2001). Similar findings were reported by Kaur et al. (2001).

Fruit circumference contributes to improved yield and parents L_1, L_5, T_3, T_4, and L_9 had the largest fruit. The highest fruit circumference was recorded in L_6 x T_4 followed by L_1 x T_2 and the lowest was in L_3 x T_3. The observations were positive and significant for 14 hybrids. Positive and negative non-significant heterosis were observed in seven and four hybrids, respectively. Seven hybrids had significant and heterobeltiosis,

Table 2. Analysis of variance for parents and hybrids for vegetative and reproductive characters.

Source	df	PH [a]	DFF	NB/P	FL	FC	NF/P	AFW	FY/P
Hybrids	39	346.5306*	54.8730*	17.4039*	5.4570*	9.9952*	161.9557*	149.5525*	0.6288*
Lines	9	973.0851*	76.5412*	40.2728*	4.9768*	20.0498*	197.8137*	328.0857*	0.9020*
Testers	3	66.6626*	17.7451*	12.1612*	9.7032*	16.6776*	234.2205*	72.4168*	0.4214*
Line x Testers	27	168.7756*	51.7756*	10.3635*	5.1453*	5.9011*	141.9736*	98.6121*	0.5608*
Error	78	85.0412	3.3519	4.3914*	0.0933	0.4478	1.8176	4.0138	0.0100

*Significant at 5% level; [a]PH, plant height (cm); DFF, days to first flowering; NB/P, number of branches per plant; FL, fruit length (cm); FC, fruit circumference (cm); NF/P, number of fruit per plant; AFW, average fruit weight (g) and FY/P, fruit yield per plant (kg).

Table 3. Average performance and magnitude of heterosis for plant height and days to first flowering in eggplant.

Entry	Average value	Plant height (cm)			Average value	Days to first flowering		
		MP	BP	SV		MP	BP	SV
Alavayal Local	93.97				78.51			
Sedapatty Local (Green)	98.83				75.43			
Kariapatty Local	90.60				77.67			
Alagarkovil Local	91.93				78.02			
Palamedu Local	83.53				73.33			
Melur Local	95.20				76.89			
Keerikai Local	96.33				71.28			
Nilakottai Local	88.93				78.63			
Singampunari Local	96.60				73.11			
Sedapatty Local (Blue)	84.93				79.62			
Annamalai	73.17				81.27			
KKM 1	66.90				68.24			
Punjab Sadabahar	79.93				73.32			
EP 65	96.43				71.45			
L_1 X T_1	95.47	14.24	1.60	30.48**	73.67	-7.79**	-9.35**	-9.35**
L_1 X T_2	102.47	27.39**	9.05	40.05**	77.18	5.19**	-1.69	-5.03**
L_1 X T_3	104.77	20.49**	11.49	43.19**	79.28	4.43*	0.98	-2.45
L_1 X T_4	125.13	31.44**	29.76**	71.03**	79.60	6.16**	1.39	-2.05
L_2 X T_1	124.20	44.42**	25.67**	69.75**	81.13	3.55*	-0.17	-0.17
L_2 X T_2	102.13	23.24**	3.33	39.58**	76.13	5.98**	0.92	-6.32**
L_2 X T_3	110.20	23.29**	11.50	50.62**	83.64	12.46**	10.88**	2.92
L_2 X T_4	101.80	4.27	3.00	39.13**	76.20	3.76*	1.02	-6.24**
L_3 X T_1	112.27	37.11**	23.91**	53.44**	82.85	4.26*	1.94	1.94
L_3 X T_2	100.50	27.62**	10.93	37.36**	84.83	16.28**	9.22**	4.38*
L_3 X T_3	99.22	16.36*	9.51	35.61**	75.16	-0.45	-3.23	-7.52**
L_3 X T_4	96.70	3.40	0.28	32.16**	74.48	-0.11	-4.10*	-8.35**
L_4 X T_1	100.17	21.34**	8.96	36.90**	70.73	-11.19**	-12.97**	-12.97**
L_4 X T_2	91.63	15.38	-0.33	25.24*	71.50	-2.22	-8.35**	-12.02**
L_4 X T_3	101.20	17.77*	10.08	38.31**	75.00	-0.89	-3.87*	-7.72**
L_4 X T_4	94.20	0.02	-2.32	28.75**	74.67	-0.09	-4.29*	-8.12**
L_5 X T_1	86.90	10.91	4.03	18.77	70.89	-8.29**	-12.77**	-12.77**
L_5 X T_2	85.53	13.72	2.39	16.90	74.26	4.91**	1.26	-8.63**
L_5 X T_3	95.60	16.97*	14.45	30.66**	78.12	6.54**	6.53**	-3.87*
L_5 X T_4	83.90	-6.76	-13.00	14.67	72.65	0.36	-0.93	-10.61**
L_6 X T_1	91.77	9.01	-3.61	25.42*	74.28	-6.07**	-8.60**	-8.60**
L_6 X T_2	85.90	5.98	-9.77	17.40	70.94	-2.24	-7.74**	-12.71**
L_6 X T_3	72.33	-17.40*	-24.02**	-1.14	71.87	-4.31*	-6.53**	-11.57**
L_6 X T_4	93.90	-2.00	-2.63	28.34**	73.55	-0.83	-4.34*	-9.50**
L_7 X T_1	96.73	14.14	0.42	32.21**	78.66	3.13	-3.21	-3.21
L_7 X T_2	103.20	26.44**	7.13	41.05**	76.05	9.02**	6.69**	-6.42**
L_7 X T_3	106.93	21.33**	11.00	46.15**	69.25	-4.22*	-5.55**	-14.79**
L_7 X T_4	97.23	0.88	0.83	32.89**	76.45	7.13**	7.00**	-5.93**
L_8 X T_1	93.77	15.69*	5.43	28.15**	68.69	-14.08**	-15.48**	-15.48**
L_8 X T_2	86.60	11.14	-2.62	18.36	78.50	6.90**	-0.17	-3.41
L_8 X T_3	96.67	14.49	8.70	32.12**	75.46	-0.68	-4.03*	-7.15**
L_8 X T_4	96.83	4.48	0.41	32.35**	87.98	17.25**	11.90**	8.26**
L_9 X T_1	86.53	1.94	-10.42	18.27	75.51	-2.18	-7.09**	-7.09**

*, **Significant at 5 and 1% level.

Table 3. Contd.

Entry	Average value	Number of branches per plant			Average value	Fruit length (cm)		
		MP	BP	SV		MP	BP	SV
L_9 X T_2	93.20	14.01	-3.52	27.38**	73.94	4.62*	1.14	-9.02**
L_9 X T_3	87.29	-1.11	-9.64	19.30	77.70	6.13**	5.97**	-4.39*
L_9 X T_4	84.33	-12.62	-12.70	15.26	72.22	-0.08	-1.22	-11.14**
L_{10} X T_1	84.25	6.57	-0.81	15.14	75.31	-6.38**	-7.33**	-7.33**
L_{10} X T_2	85.33	12.40	0.47	16.63	76.38	3.32	-4.07*	-6.01**
L_{10} X T_3	87.27	5.86	2.75	19.27	78.54	2.71	-1.36	-3.36
L_{10} X T_4	82.50	-9.02	-14.45	12.76	82.21	8.84**	3.25	1.16
SEd	7.25	6.23	7.20	1.52		1.31	1.51	
Alavayal Local	21.13				7.44			
Sedapatty Local (Green)	22.32				7.54			
Kariapatty Local	16.36				6.93			
Alagarkovil Local	20.49				6.53			
Palamedu Local	20.04				7.87			
Melur Local	21.89				7.14			
Keerikai Local	22.11				7.79			
Nilakottai Local	21.74				10.23			
Singampunari Local	17.88				5.41			
Sedapatty Local (Blue)	21.62				6.92			
Annamalai	24.18				11.61			
KKM 1	15.31				5.25			
Punjab Sadabahar	18.50				6.85			
EP 65	18.01				8.07			
L_1 X T_1	26.36	16.36**	9.03	9.03	6.58	-30.74**	-43.28**	-43.28**
L_1 X T_2	23.70	27.71**	12.15	-1.99	6.92	9.30**	-6.57*	-40.41**
L_1 X T_3	20.02	1.03	-5.25	-17.19**	6.83	-4.16	-7.74*	-41.15**
L_1 X T_4	19.63	0.32	-7.08	-18.79**	8.17	5.58*	1.20	-29.61**
L_2 X T_1	19.12	-17.74**	-20.90**	-20.90**	7.78	-18.73**	-32.97**	-32.97**
L_2 X T_2	19.74	3.11	-11.53	-18.34**	5.86	-8.39**	-22.28**	-49.51**
L_2 X T_3	18.81	-7.82	-15.70*	-22.18**	6.63	-7.85**	-12.07**	-42.88**
L_2 X T_4	19.60	-2.82	-12.19	-18.94**	8.00	2.48	-0.91	-31.07**
L_3 X T_1	22.87	12.83*	-5.40	-5.40	6.16	-33.57**	-46.96**	-46.96**
L_3 X T_2	20.71	28.08**	26.58**	-14.33*	6.52	7.03*	-5.92	-43.83**
L_3 X T_3	16.80	-3.63	-9.21	-30.51**	6.97	1.16	0.58	-39.95**
L_3 X T_4	19.46	13.22	8.03	-19.51**	6.54	-12.77**	-18.95**	-43.62**
L_4 X T_1	26.52	18.75**	9.69	9.69	6.34	-30.11**	-45.40**	-45.40**
L_4 X T_2	25.50	39.84**	24.45**	5.47	7.34	24.62**	12.46**	-36.76**
L_4 X T_3	17.25	-11.54	-15.83*	-28.66**	5.88	-12.14**	-14.21**	-49.37**
L_4 X T_4	18.09	-6.05	-11.73	-25.19**	9.84	34.79**	21.88**	-15.22**
L_5 X T_1	23.09	4.45	-4.49	-4.49	6.00	-38.41**	-48.33**	-48.33**
L_5 X T_2	27.09	50.41**	35.19**	12.04*	6.41	-2.29	-18.52**	-44.77**
L_5 X T_3	26.78	38.97**	33.65**	10.77	6.74	-8.40**	-14.32**	-41.93**
L_5 X T_4	25.92	36.24**	29.36**	7.21	7.86	-1.38	-2.64	-32.28**
L_6 X T_1	23.07	0.16	-4.58	-4.58	4.36	-53.46**	-62.41**	-62.41**
L_6 X T_2	28.53	50.67**	30.33**	18.01**	10.15	63.75**	42.09**	-12.55**
L_6 X T_3	25.08	24.18**	14.57*	3.74	6.32	-9.72**	-11.57**	-45.58**
L_6 X T_4	24.20	21.29**	10.55	0.10	5.44	-28.54**	-32.66**	-53.16**
L_7 X T_1	23.69	2.35	-2.03	-2.03	5.58	-42.47**	-51.92**	-51.92**
L_7 X T_2	27.53	44.55**	24.51**	13.87*	7.88	20.80**	1.11	-32.11**
L_7 X T_3	22.75	12.02*	2.88	-5.91	5.74	-21.60**	-26.35**	-50.55**
L_7 X T_4	23.85	18.87**	7.85	-1.36	7.90	-0.46	-2.19	-31.96**
L_8 X T_1	26.83	16.88**	10.99	10.99	6.87	-37.10**	-40.84**	-40.84**
L_8 X T_2	23.02	22.07**	5.90	-4.77	5.89	-23.90**	-42.41**	-49.25**
L_8 X T_3	22.22	10.43	2.21	-8.09	10.70	25.32**	4.63*	-7.81**
L_8 X T_4	16.21	-18.45**	-25.44**	-32.95**	8.83	-3.46	-13.62**	-23.89**
L_9 X T_1	28.24	34.29**	16.81**	16.81**	5.50	-35.34**	-52.61**	-52.61**
L_9 X T_2	19.49	15.14*	9.02	-19.37**	5.69	6.82	5.30	-50.95**
L_9 X T_3	22.91	25.94**	23.82**	-5.24	6.78	10.63**	-1.02	-41.59**
L_9 X T_4	20.75	15.60*	15.17	-14.19*	6.74	0.00	-16.52**	-41.93**
L_{10} X T_1	15.29	-33.24**	-36.77**	-36.77**	5.91	-36.20**	-49.08**	-49.08**
L_{10} X T_2	19.97	6.25	-7.60	-17.39**	6.30	3.45	-9.01**	-45.75**
L_{10} X T_3	18.83	-6.15	-12.91*	-22.13**	5.12	-25.64**	-26.01**	-55.89**
L_{10} X T_4	18.15	-8.40	-16.04*	-24.93**	5.62	-25.03**	-30.39**	-51.58**
SEd	1.65	1.22	1.41		0.23	0.20	0.23	
CD at 1%	4.25				0.60			

*, **Significant at 5 and 1% level.

Table 3. Contd.

Entry	Average value	Average fruit weight (g)			Average value	Fruit yield per plant (kg)		
		MP	BP	SV		MP	BP	SV
CD at 5%	3.23		0.46	CD at 5%	3.23			
Alavayal Local	66.32				1.72			
Sedapatty Local (Green)	56.09				1.86			
Kariapatty Local	41.05				1.27			
Alagarkovil Local	46.01				1.26			
Palamedu Local	81.66				1.91			
Melur Local	55.72				1.75			
Keerikai Local	65.76				1.79			
Nilakottai Local	50.01				1.27			
Singampunari Local	34.94				1.16			
Sedapatty Local (Blue)	54.17				1.37			
Annamalai	55.9				2.12			
KKM 1	42.42				1.46			
Punjab Sadabahar	50.34				1.56			
EP 65	53.38				1.36			
L_1 X T_1	69.40	13.57**	4.65	24.15**	2.47	28.65**	16.33**	16.33**
L_1 X T_2	54.62	0.47	-17.63**	-2.28	1.35	-15.13**	-21.55**	-36.58**
L_1 X T_3	65.78	12.77**	-0.81	17.67**	1.35	-17.60**	-21.36**	-36.42**
L_1 X T_4	51.83	-11.14**	-21.84**	-7.27*	1.45	-5.42	-15.34**	-31.55**
L_2 X T_1	48.00	-14.28**	-14.42**	-14.13**	2.07	3.77	-2.67	-2.67
L_2 X T_2	54.32	10.29**	-3.15	-2.82	1.42	-14.17**	-23.48**	-32.97**
L_2 X T_3	57.82	8.64**	3.08	3.43	2.14	24.95**	14.87**	0.63
L_2 X T_4	52.24	-1.83	-6.86*	-6.54*	1.56	-2.80	-15.95**	-26.37**
L_3 X T_1	43.50	-10.26**	-22.18**	-22.18**	1.45	-14.45**	-31.71**	-31.71**
L_3 X T_2	44.44	6.49	4.76	-20.50**	0.99	-27.05**	-31.81**	-53.22**
L_3 X T_3	61.99	35.65**	23.13**	10.89**	1.74	23.11**	11.54*	-18.05**
L_3 X T_4	47.41	3.76	-5.82	-15.19**	0.93	-29.35**	-31.70**	-56.36**
L_4 X T_1	60.91	19.54**	8.97**	8.97**	2.40	41.73**	13.03**	13.03**
L_4 X T_2	52.64	19.04**	14.39**	-5.84*	2.32	70.34**	59.04**	9.11*
L_4 X T_3	53.38	10.79**	6.03	-4.51	1.49	5.79	-4.27	-29.67**
L_4 X T_4	58.18	20.76**	15.57**	4.08	1.92	46.31**	41.28**	-9.73*
L_5 X T_1	66.13	-3.85	-19.02**	18.30**	1.71	-15.44**	-19.62**	-19.62**
L_5 X T_2	59.64	-3.87	-26.97**	6.68*	2.34	38.87**	22.30**	10.20**
L_5 X T_3	56.04	-15.10**	-31.38**	0.24	2.36	36.08**	23.52**	11.30**
L_5 X T_4	51.17	-22.47**	-37.34**	-8.47**	2.21	35.17**	15.51**	4.08
L_6 X T_1	51.64	-7.47**	-7.62**	-7.62**	1.48	-23.65**	-30.30**	-30.30**
L_6 X T_2	55.96	14.05**	0.44	0.11	2.24	39.56**	27.76**	5.49
L_6 X T_3	53.48	0.84	-4.02	-4.34	1.35	-18.31**	-22.81**	-36.26**
L_6 X T_4	51.00	-3.83	-8.47**	-8.77**	1.68	7.82	-4.37	-21.04**
L_7 X T_1	56.55	-7.04**	-14.01**	1.16	1.13	-42.25**	-46.78**	-46.78**
L_7 X T_2	69.49	28.46**	5.67*	24.31**	2.85	75.36**	59.03**	34.07**
L_7 X T_3	54.50	-6.11*	-17.12**	-2.50	1.43	-14.43**	-19.93**	-32.50**
L_7 X T_4	57.67	-0.65	-12.30**	3.17	1.74	10.38*	-2.98	-18.21**
L_8 X T_1	42.04	-20.61**	-24.79**	-24.79**	2.26	33.14**	6.28	6.28
L_8 X T_2	42.74	-7.51*	-14.53**	-23.54**	1.66	21.91**	13.96*	-21.82**
L_8 X T_3	40.84	-18.60**	-18.87**	-26.94**	1.04	-26.18**	-33.12**	-50.86**
L_8 X T_4	49.54	-1.27	-1.60	-11.38**	2.06	57.31**	52.09**	-2.83
L_9 X T_1	46.66	2.73	-16.53**	-16.53**	2.29	39.15**	7.69*	7.69*
L_9 X T_2	46.87	21.17**	10.49**	-16.15**	1.73	31.81**	18.54**	-18.68**
L_9 X T_3	56.43	32.34**	12.09**	0.95	1.22	-10.40*	-21.79**	-42.54**
L_9 X T_4	50.54	18.54**	0.40	-9.58**	1.42	12.43*	4.42	-33.28**
L_{10} X T_1	57.01	3.59	1.98	1.98	1.12	-35.82**	-47.25**	-47.25**
L_{10} X T_2	52.21	8.11**	-3.61	-6.60*	1.85	30.81**	26.77**	-13.03**
L_{10} X T_3	61.70	18.07**	13.91**	10.38**	1.43	-2.51	-8.55	-32.81**
L_{10} X T_4	56.59	8.29**	4.47	1.23	1.45	6.73	6.34	-31.55**
SEd	1.60	1.39	1.60		0.08	0.07	0.08	
CD at 1%	4.15				0.21			
CD at 5%	3.15				0.16			

*, **Significant at 5% and 1% level.

24 had significant and negative heterosis. Thirty-one (31) hybrids had significant and positive heterosis over the standard variety. Four hybrids had non-significant and negative values. The findings corroborate the results of

Table 4. Genotypic correlation between fruit yield and growth characters in eggplant.

Parameter	Days to first flowering	Number of branches per plant	Fruit yield per plant (kg)
Plant height (cm)	0.454*	-0.125	0.007
Days to first flowering		-0.385*	-0.211
Number of branches per plant			0.598*

*Significant at 5% level.

Nalini (2007).

The number of fruit per plant influences yield. The lowest number of fruit per plant was in L_5 and the highest in T_1 followed by L_9 among parents. Nineteen crosses, L_1 x T_1, L_2 x T_1, L_2 x T_3, L_4 x T_1, L_4 x T_2, L_4 x T_4, L_5 x T_2, L_5 x T_3, L_5 x T_4, L_6 x T_2, L_6 x T_4, L_7 x T_2, L_7 x T_4, L_8 x T_1, L_8 x T_2, L_8 x T_4, L_9 x T_1, L_9 x T_2 and L_{10} x T_2 exhibited positive heterosis in the desirable direction over the mid-parent. Expression of heterosis over the better parent in the positive direction occurred in 14 crosses. Significant heterosis over comer-cial check was recorded in 33 hybrids with 9 had positive and 23 had negative heterosis. Considerable positive heterosis in different cross combinations were also reported by Chowdhury et al. (2010).

The highest single fruit weight was for L_7 x T_2 followed by L_1 x T_1 and the lowest was in L_8 x T_3. Of 40 hybrids, 17 had significant desirable heterosis over the mid-parent in the positive direction. Only 7 hybrids had significant heterobeltiosis. In 8 hybrids, heterosis was significant and in the positive direction over the standard variety. The heterosis over the better and standard parents was negative for fruit weight. Similar findings reported by Nalinidharwad et al. (2011) and Patil et al. (2001) lend support to the present results. This trend is not a constraint, because smaller sized eggplant fruit are preferred in South India and hybrids with smaller and more fruit could be selected.

The ultimate interest of the breeder is to get high yield. An appreciable amount of heterosis in F_1s over the mid-parent value occurred for fruit yield per plant. The T_1 parent had the highest yield followed by L_5 and L_2, while the lowest yield was for L_9. Fruit yield per plant showed a wide range among hybrids. Among the 40 hybrids, 19 had significant positive heterosis over the mid-parent. The hybrid from the cross L_7 x T_2 had the highest magnitude of heterosis in the positive direction followed by L_4 x T_2, L_8 x T_4 and L_4 x T_4. Most crosses involving T_2 as tester parent had significant, positive, heterosis over the mid-parent. This agrees with Ramesh Kumar et al. (2013).

Association analysis

Genotypic correlation coefficients varied depending on character (Tables 4 to 8). Of 15 characters studied, only numbers of fruit per plant, number of branches per plant and average fruit weight had significant association with fruit yield at phenotypic and genotypic levels (Prabakaran, 2010).

Fruit yield had significant negative association with fruit borer infestation at both levels. This trait could be considered as an important criterion for selection for fruit yield. Total phenol content had considerable non-significant positive correlation with fruit yield per plant followed by fruit length, fruit circumference and shoot borer infestation. During selection these traits can be considered to improve fruit yield. There were significant, and positive, correlations for plant height with days to first flowering, while days to first flowering significantly, and negatively, correlated with numbers of branches per plant. As days to first flowering decreases, there will be an increase in number of branches per plant. Fruit pedicel length had a significant, and positive, correlation with clayx length. Fruit circumference was significantly, and positively, associated with average fruit and average fruit weight may result in simultaneous improvement of fruit yield per plant (Thangamani and Jansirani, 2012). These cha-racters are highly reliable components of fruit yield and could be utilized as yield indicators during selection. Days to first flowering, fruit pedicel length, calyx length, fruit borer infestation and ascorbic acid, an important quality trait, were negatively associated with fruit yield per plant. Selection for this trait will result in reduction weight. Similarly, the association between shoot borer infestation and little leaf incidence was positive and significant. Selection for this trait will result in reduction of fruit yield, number of branches per plant, number of fruit per plant of fruit yield.

Path coefficient analysis

The path coefficient analysis permits the separation of direct effect from indirect effects through other related traits by partitioning genotypic correlation coefficients. Plant height, number of branches per plant, fruit length, fruit pedicel length, number of fruit per plant, average fruit weight and little leaf incidence had positive direct effect on yield (Table 9).

Direct selection for these characters are likely will bring about an overall improvement in fruit yield per plant. The residual effect determines how causal factors account

Table 5. Genotypic correlation between fruit yield and fruit characters in eggplant.

Parameter	Fruit pedicel length (cm)	Fruit circumference (cm)	Calyx length (cm)	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (kg)
Fruit length (cm)	0.101	-0.185	0.181	0.139	0.094	0.200
Fruit pedicel length (cm)	-	0.034	0.248*	-0.185	0.088	-0.124
Fruit circumference (cm)	-	-	-0.011	0.061	0.273*	0.154
Calyx length (cm)	-	-	-	-0.094	0.161	-0.023
Number of fruit per plant	-	-	-	-	-0.148	0.836*
Average fruit weight (g)	-	-	-	-	-	0.380*

*Significant at 5% level.

Table 6. Phenotypic correlation between fruit yield and fruit characters in eggplant.

Parameter	Fruit pedicel length (cm)	Fruit circumference (cm)	Calyx length (cm)	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (kg)
Fruit length (cm)	0.084	-0.169	0.147	0.150	0.085	0.205
Fruit pedicel length (cm)	-	0.027	0.247*	-0.186	0.084	-0.125
Fruit circumference (cm)	-	-	-0.019	0.064	0.247*	0.147
Calyx length (cm)	-	-	-	-0.108	0.161	-0.034
Number of fruit per plant	-	-	-	-	-0.140	0.831*
Average fruit weight (g)	-	-	-	-	-	0.381*

*Significant at 5% level.

Table 7. Genotypic correlation between fruit yield, pest and disease incidence and quality characters in eggplant.

Parameter	Fruit borer infestation (%)	Little leaf incidence (%)	Ascorbic acid content (mg/100g)	Total phenols content (mg/100g)	Fruit yield per plant (kg)
Shoot borer infestation (%)	-0.007	0.400*	-0.053	0.141	0.102
Fruit borer infestation (%)	-	-0.048	0.084	0.187	-0.280*
Little leaf incidence (%)	-	-	0.048	0.208	0.043
Ascorbic acid content (mg/100 g)	-	-	-	-0.151	-0.045
Total phenols content (mg/100 g)	-	-	-	-	0.227

*Significant at 5% level.

Table 8. Phenotypic correlation between fruit yield, pest and disease incidence and quality characters in eggplant.

Parameter	Fruit borer infestation (%)	Little leaf incidence (%)	Ascorbic acid content (mg/100 g)	Total phenols content (mg/100 g)	Fruit yield per plant (kg)
Shoot borer infestation (%)	-0.009	0.393*	-0.047	0.137	0.094
Fruit borer infestation (%)		-0.054	0.065	0.168	-0.275*
Little leaf incidence (%)			0.057	0.203	0.047
Ascorbic acid content (mg/100 g)				-0.151	-0.036
Total phenols content (mg/100 g)					0.215

* Significant at 5% level.

Table 9. Direct and indirect effects of different characters on fruit yield in eggplant.

Character	X1[a]	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	Fruit yield per plant
X1	0.0072	-0.0123	-0.0022	0.0000	-0.0006	-0.0012	0.0019	0.0429	-0.0058	0.0025	0.0119	0.0061	-0.0040	-0.0055	0.039
X2	0.0027	-0.0328	-0.0130	0.0001	-0.0002	0.0037	0.0012	-0.0581	-0.0455	0.0015	-0.0035	0.0042	0.0005	0.0027	-0.138
X3	-0.0002	0.0073	0.0583	-0.0000	-0.0002	-0.0046	0.0012	0.0370	0.0864	0.0000	-0.0096	0.0041	-0.0039	-0.0045	0.166
X4	0.0008	-0.0021	0.0152	0.0003	-0.0005	0.0025	0.0005	-0.0304	0.1915	0.0025	0.0111	-0.0018	0.0013	-0.0025	0.169
X5	0.0001	-0.0047	-0.0030	0.0011	0.0004	0.0070	-0.0011	0.0384	0.0539	0.0034	0.0084	-0.0042	0.0029	0.0027	0.100
X6	-0.0010	0.0016	-0.0035	0.0001	0.0047	-0.0012	-0.0015	-0.1185	0.0503	0.0034	0.0035	-0.0062	-0.0013	0.0055	-0.062
X7	0.0002	0.0032	0.0071	-0.0002	0.0001	-0.0379	0.0000	0.0898	0.1571	0.0020	0.0064	-0.0002	-0.0000	-0.0001	0.229
X8	-0.0022	0.0065	-0.0115	0.0002	0.0011	0.0004	-0.0064	-0.0532	0.0928	0.0055	-0.0005	-0.0118	0.0013	0.0058	0.030
X9	0.0003	0.0022	0.0025	0.0000	-0.0006	-0.0040	0.0004	0.8516	-0.0525	-0.0004	0.0002	0.0011	-0.0004	-0.0007	0.801*
X10	-0.0000	0.0026	0.0087	0.0001	0.0004	-0.0103	-0.0010	-0.0777	0.5758	0.0024	0.0206	-0.0003	-0.0015	-0.0040	0.509*
X11	-0.0015	0.0041	-0.0004	-0.0003	-0.0013	0.0061	0.0028	0.0275	-0.1143	-0.0124	0.0010	0.0088	0.0010	-0.0024	-0.077
X12	-0.0015	-0.0020	0.0098	-0.0001	-0.0002	0.0042	-0.0000	-0.0042	-0.2072	0.0002	-0.0572	-0.0001	-0.0010	0.0025	-0.253*
X13	0.0019	-0.0060	0.0106	-0.0002	-0.0012	0.0004	0.0033	0.0408	-0.0074	-0.0048	0.0002	0.0229	-0.0003	-0.0044	0.057
X14	0.0020	0.0012	0.0154	-0.0002	0.0004	-0.0001	0.0005	0.0237	0.0615	0.0009	-0.0038	0.0005	-0.0148	0.0035	0.093
X15	0.0021	0.0046	0.0137	-0.0001	-0.0013	-0.0003	0.0019	0.0324	0.1216	-0.0016	0.0075	0.0053	0.0027	-0.0191	0.167

*Significant at 5% level; Residual effect, 0.102; Diagonal values, direct effects; Half diagonal values, indirect effects. [a] X1, Plant height (cm); X2, Days to first flowering; X3, Number of branches per plant; X4, Fruit length (cm); X5, Fruit pedicel length (cm); X6, Fruit circumference (cm); X7, Calyx length (cm); X8, Number of fruit per plant; X9, Average fruit weight (g); X10, Shoot borer infestation (%); X11, Fruit borer infestation (%); X12, Little leaf incidence (%); X13, Ascorbic acid content (mg/100g); and X14, Total phenols content (mg/100g).

for variability of the dependent factor, that is, fruit yield per plant in this study. The residual effect was only 0.102, accounting for 97.50% of variability in fruit yield per plant, was explained by the 15 variables included in the study.

The characters studied by path analysis for yield appear to be appropriate. Plant height, number of branches per plant, fruit length, fruit pedicel length, number of fruit per plant, average fruit weight and little leaf incidence are important characters to bring about overall improvement in fruit yield per plant. Similar trend of findings were also obtained by Thangamani and Jansirani (2012) for fruit yield per plant, number of branches per plant and average fruit weight in brinjal.

Conclusion

Promising lines are to be used to obtain higher yield, earliness and increased fruit number. Due to high heterosis the importance of non-additive genetic effects in expression can be inferred. The establishment of a population with a wide genetic base, using recurrent selection methods for increasing combining ability, will lead to future new lines which result in hybrids superior to those studied. The hybrids L7xT2, L1xT1, L4 xT1, L5xT3, L5xT2, L8 x T4 and L4 x T2 had the highest values over standard variety heterosis. These hybrids can be utilized for selecting superior desirable segregants in later generations. Correlation and path analysis indicated that more fruit per plant with heavier weight are contributors to improved yield. At the outset comprehensive results obtained from the correlation and path analysis indicated that more number of fruits per plant with more fruit weight are outstanding contributors made by the hybrids for yield per plant. Therefore, while selecting the hybrids due weightage may given to the above said traits for the overall improvement of fruit yield.

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