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HETEROSIS ANALYSIS FOR SEED YIELD AND YIELD ATTRIBUTING TRAITS IN COWPEA (*VIGNA UNGUICULATA* L. WALP) UNDER MULTI-ENVIRONMENT CONDITIONS

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ABSTRACT

The present study evaluated heterosis for seed yield and its component traits in cowpea (*Vigna unguiculata* L. Walp) under multi-environment conditions. A total of 36 F_1 hybrids developed through a Line × Tester design (12 lines × 3 testers) were assessed along with parents and standard checks (Kashi Nidhi and RC-101) in a RBD across three environments during kharif 2023–24. Significant variation among genotypes was observed for all traits. High heterosis was recorded for seed yield per plant, pods per plant, seeds per pod and 100-seed weight. Crosses $L_5 \times T_2$, $L_9 \times T_1$ and $L_7 \times T_3$ exhibited superior performance. The predominance of non-additive gene action indicated the potential of heterosis breeding for developing high-yielding cowpea genotypes.

***Keywords* :** Cowpea, Heterosis, Seed yield, Line × Tester, Hybrid vigour, Non-additive gene action.

Introduction

Cowpea (*Vigna unguiculata* L. Walp) is a self-pollinated, protein-rich multipurpose legume widely grown in tropical and subtropical regions, possessing a chromosome number of 2n = 2x = 22 (Darlington and Wylie, 1955). It exhibits considerable genetic diversity, being classified into cultivated and wild subspecies (Verdcourt, 1970), and serves as an important source of plant protein (~25%), often referred to as “vegetable meat” (Sharma *et al.*, 2022). In India, particularly Rajasthan, it plays a significant role in food and nutritional security, In Rajasthan, average area under cowpea in 2023-24 was 93,619 ha with 38,152 tonnes of average production and 408 kg ha^{-1} average productivity (Directorate of Economics and Statistics, 2023–24). Heterosis, defined as the superiority of F_1 hybrids over parents (Shull, 1914), is a key approach for yield improvement, though its exploitation in cowpea remains limited. Understanding heterotic expression is essential for identifying superior crosses and developing high-yielding segregants (Get *et al.*, 2021). Therefore, the present study aimed to evaluate heterosis for seed yield and its component traits in cowpea under multi-environment conditions.

Materials and Methods

The experimental material comprised 12 lines and 3 testers crossed in a Line × Tester design (Kempthorne, 1957) to generate 36 F_1 hybrids. These hybrids, along with parents and two standard checks, were evaluated in a RBD design with three replications across three environments during kharif 2023–24. Observations were recorded for yield and its component traits, including flowering, maturity, plant height, pods per plant, seeds per pod, 100-seed weight, seed yield and related parameters. The experimental material consisted of 12 lines and 3 testers, which were crossed in a L × T mating design to generate 36 F_1 hybrids by conventional method of hybridization.

These hybrids, along with their parents and two standard checks (Kashi Nidhi and RC-101), were evaluated in a RBD design (Nadarajan and Gunasekaran 2005) with three replications across three environments (Instructional Farm, RCA,Udaipur (E_1), KVK, Chittorgarh (E_2) and Instructional Farm, CTAE, MPUAT, Udaipur (E_3). The experimental material consisted of 12 lines and 3 testers *viz.* IC-249132 (L_1), IC-249133 (L_2), IC-249140 (L_3), IC-249141 (L_4), IC-249589 (L_5), IC-25287 (L_6), IC-259063 (L_7), IC-259064 (L_8), IC-2816 (L_9), IC-2918 (L_{10}), RC-19 (L_{11}), CPD-119 (L_{12}), Pusa Sukanya (T_1), Swarna Mukut (T_2), Kashi Kanchan (T_3), obtained from NBPGR, Regional Station, Jodhpur and Agricultural Research Station, Bikaner and their 36 F_1 hybrids obtain from Instructional Farm, RCA, Udaipur. Each genotype was grown in a single row with recommended agronomic practices. Observations were recorded on days to 50 per cent flowering, days to maturity, plant height, number of primary branches per plant, number of cluster per plant, number of mature pods per plant, pod length, pod diameter, number of seeds per pod, 100-seed weight, seed yield per plant, harvest index, seed length, seed dimeter, leaf area index, chlorophyll content at 50 per cent flowering and protein content. Heterosis was estimated as per cent increase or decrease of F_1 over mid parent (relative heterosis), better parent (heterobeltiosis) and standard checks (standard heterosis). Heterosis (over mid-parent), heterobeltiosis (over better parent), and economic heterosis were computed following the methodologies proposed by Shull (1948), Fonseca and Patterson (1968), and Meredith and Bridge (1972), respectively, both individually and across various environments.

$$\textit{Heterosis}\ (\%) = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\textit{Heterobeltiosis}\ (\%) = \frac{\left(\overline{F_1} - \overline{BP}\right)}{\overline{BP}}\ x\ 100$$

$$\textit{Economic heterosis}\ (\%) = \frac{\left(\overline{F_1} - \overline{BC}\right)}{\overline{BC}}\ x\ 100$$

Where, F1 = Mean performance of the F1 hybrid, MP= Mean value of the parents (P1 and P2) of a hybrid, BP= Mean value of better parent.

Result and Discussion

The pooled analysis indicated that the mean sum of squares for genotypes, environments, parents, crosses, and parents' *vs* crosses were significant for all traits, except for days to 50 per cent flowering, days to maturity, pod diameter, number of seeds per pod, seed diameter and chlorophyll content at 50 per cent flowering which was not significant due to the parent's *vs* crosses. (Table:1) These variance results align with findings reported by Gupta *et al.* (2020), Get *et al.* (2021) and Adie *et al.* (2023).

Estimates of economic heterosis for yield-contributing traits indicated that the only one cross L_9 x T_1 demonstrated the highest hybrid vigour compared to the standard check for seed yield per plant in only one E_3 environment, for harvest index in E_2 environments and for number of cluster per plant in three environments. Cross L_7 x T_3 also exhibited maximum economic heterosis for number of seeds per pod. Cross L_6 x T_3 showed maximum economic heterosis for 100 seed weight, meanwhile, cross L_{10} x T_3 exhibited maximum heterosis for harvest index. Cross L_5 x T_2 showed maximum economic heterosis for the number of mature pods per plant. For number of cluster per plant, cross L_9 x T_1 exhibited the highest economic heterosis and cross L_{10} x T_1 for number of primary branches per plant. The highest economic heterosis was observed with cross L_7 x T_1, L_8 x T_1, L_3 x T_2, L_8 x T_2 and L_9 x T_2 for pod diameter. Cross L_1 x T_2 showed maximum hybrid vigour over the standard check for pod length. In terms of traits related to earliness, the highest economic heterosis was observed with cross L_9 x T_1 for early flowering and L_7 x T_2 for early maturity and L_7 x T_2 for seed length. For plant height, L_{11} x T_2 exhibited the highest economic heterosis Cross L_9 x T_2 showed maximum hybrid vigour over the standard check for protein content. L_1 x T_1 demonstrated the highest economic heterosis for the chlorophyll content at 50 per cent flowering. For leaf area index, L_8 x T_1 exhibited the maximum economic. (Table: 3-7) These findings are consistent with prior research by Nag *et al.* (2020), Talape *et al.* (2020), Shirisha *et al.* (2022) and Matjeke *et al.* (2025) regarding standard heterosis in Cowpea.

In this study, among yield and yield-contributing traits, four hybrids showed significant positive heterobeltiosis (Table-3-7), particularly for seed yield plant per plant. The cross L_6 x T_3 demonstrated the highest significant heterobeltiosis for seed yield per plant. Positive heterobeltiosis was observed significantly in 14 crosses for plant height, 6 crosses for number of primary branches per plant, 6 crosses for number of cluster per plant, 5 crosses for number of mature pods per plant, 10 crosses for pod length, 7 crosses for pod diameter, 9 crosses for number of seeds per pod, 7 crosses for 100-seed weight, 5 crosses for seed per yield plant, 4 crosses for harvest index, 5 crosses for seed length, 6 crosses for seed diameter, one cross for leaf area index, 5 crosses for chlorophyll content at 50 per cent flowering and 9 crosses for protein content. In terms of maturity-related traits, 17 crosses showed significant negative heterobeltiosis for days to 50 per cent flowering, and 19 crosses for days to maturity. (Table: 3-7) Similar findings were reported by Verma *et al.* (2020), Talape *et al.* (2020), Get *et al.* (2021), Krisnawati *et al.* (2022) and Adie *et al.* (2023).

The highest significant positive relative heterosis was demonstrated by 11 crosses for seed yield per plant, with cross L_9 x T_1 showing the maximum heterosis across environments. For other yield-related traits, significant positive relative heterosis was observed in 24 crosses for plant height, 10 crosses for number of primary branches per plant, 10 crosses for number of cluster per plant, 11 crosses for number of mature pods per plant, 15 crosses for pod length, 6 crosses for pod diameter, 13 crosses for number of seeds per pod, 12 crosses for 100-seed weight, 11 crosses for seed yield per plant, 9 crosses for harvest index, 9 crosses for seed length, 13 crosses for seed diameter, 4 crosses for leaf area index, 10 crosses for chlorophyll content at 50 per cent flowering and 18 crosses for protein content. In terms of maturity-related traits, 9 crosses showed significant negative relative heterosis for days to 50 per cent flowering and 7 crosses for days to maturity. Most crosses for seed yield per plant and yield-contributing traits showed significant positive relative heterosis, indicating the dominance of genes with positive effects on these traits. In contrast, for maturity-related traits, the majority of crosses exhibited significant negative relative heterosis, suggesting dominance of genes with negative effects on these traits. (Table: 3-7) These findings align with similar results reported by Pallavi *et al.* (2020), Verma *et al.* (2020), Gupta *et al.* (2020), Nag *et al.* (2020), Get *et al.* (2021), Shirisha *et al.* (2022), Krisnawati *et al.* (2022) and Adie *et al.* (2023).

Conclusion

The present investigation confirmed the significant role of heterosis in enhancing seed yield and its associated traits in cowpea under multi-environment conditions. The predominance of non-additive gene action suggests that hybrid breeding is an effective strategy for yield improvement. Crosses such as $L_5 \times T_2$, $L_9 \times T_1$ and $L_7 \times T$ emerged as superior due to their consistent and high heterotic performance across environments. These hybrids possess strong potential for exploitation in breeding programmes to develop high-yielding, stable and adaptable cowpea genotypes, and can further be utilized for selecting desirable transgressive segregants in advanced generations.

Table 1: Pooled analysis of variance for different characters in cowpea

Characters	Source of variation					
	Replication	**Genotype**	**Parents**	**Crosses**	**P v/s C**	**Pooled Error**
d.f.	2	50	14	35	1	300
Days to 50 per cent flowering	0.01	111.48**	97.32**	120.31**	0.73	1.56
Days to maturity (No.)	15.29	260.01**	252.79**	269.99**	11.79	15.2
Plant height (cm)	0.02	3852.32**	4478.73**	3690.22**	755.95**	1.33
Number of primary branches per plant	0.44	32.97**	27.03**	35.85**	15.51**	0.29
Number of cluster per plant	1.39	560.41**	586.93**	564.19**	56.76**	0.78
Number of mature pods per plant	0.36	447.38**	483.4**	434.26**	402.24**	0.76
Pod length (cm)	3.1**	48.47**	30.7**	56.84**	4.25**	0.46
Pod diameter (cm)	0.0042	0.0067**	0.0054**	0.0073**	0.0012	0.0007
Number of seeds per pod	0.1	14.63**	30.84**	43.31**	-1215.97	0.53
100 seed weight (gm)	0.21	48.77**	37.01**	52.45**	84.63**	0.65
Seed yield per plant	17.88	377.02**	383.41**	373.02**	427.4**	2.32
Harvest index (%)	10.47	550.09**	617.38**	519.77**	669.15**	0.96
Seed length (cm)	0.0029	0.0644**	0.0695**	0.0639**	0.0087**	0.0008
Seed diameter (cm)	0.0139	0.0073**	0.006**	0.008**	0.0005	0.0002
Leaf area index	47.47	793.14**	715.34**	787.68**	2073.3**	59.1
Chlorophyll content at 50 per cent flowering	18.14	203.73**	300.47**	170.18**	23.3	21.89
Protein content	2.98	30.51**	30.23**	30.18**	46.25**	1.96

*, ** Significant at 5% and 1%, respectively

Table 2: Range of mean and the heterosis % over Mid parent (MP) and Better parent (BP) for different characters in cowpea

Characters	Range of mean			Range of heterosis % over		Range of standard checks
	Line	Tester	Crosses	MP	BP	
Days to 50 per cent flowering	37.90-50.01	42.19-44.03	36.65-50.58	-19.99-20.11	-24.87-2.56	38.14-39.16
Days to maturity (No.)	72.17-83.21	64.68-74.27	63.48-84.35	-11.70-22.31	-17.63-4.55	65.24-68.56
Plant height (cm)	55.21-109.58	36.44-59.51	42.98-109.50	-49.16-106.7	2.96-88.93	44.58-56.04
Number of primary branches per plant	4.4-9.56	6.66-9.87	4.37-10.93	-53.55-59.54	6.03-56.88	10.22-10.68
Number of cluster per plant	7.33-36.07	18.43-22.2	7.11-36.81	-75.6-111.1	5.1-70.31	21.70-33.27
Number of mature pods per plant	14.23-35.64	18.08-33.02	14.07-37.32	-58.48-72.65	8.57-70.97	33.67-34.52
Pod length (cm)	9.75-15.72	9.11-10.81	7.07-18.84	-33.52-75.09	5.71-67.23	7.72-12.03
Pod diameter (cm)	0.40-0.49	0.42-0.44	0.39-0.49	-14.18-18.81	4.70-16.76	0.41-0.44
Number of seeds per pod	8.83-15.32	9.31-10.09	6.9-15.91	-40.57-70.48	5.89-66.17	7.01-11.87
100 seed weight (gm)	8.76-13.73	11.48-16.9	8.9-16.9	-24.81-61.83	8.1-46.02	11.07-17.20
Seed yield per plant	17.34-38.46	24.33-34.7	17.27-37.47	-50.53-42.86	4.56-37.45	34.11-37.52
Harvest index (%)	8.09-33.57	15.56-30.75	7.74-33.03	-74.27-87.85	7.26-35.01	21.34-29.80
Seed length (cm)	0.50-0.79	0.69-0.85	0.54-0.87	-25.14-33.05	5.86-25.08	0.65-0.69
Seed diameter (cm)	0.24-0.32	0.24-0.28	0.23-0.33	-22.99-34.41	7.79-32.88	0.25-0.27
Leaf area index	52.91-87.08	76.12-88.76	52.74-88.16	-33.34-24.46	10.79	58.94-72.13
Chlorophyll content at 50 per cent flowering	42.77-60.80	43.30-60.40	47.20-62.31	-21.62-27.05	8.32-17.51	45.80-47.58
Protein content	17.51-22.47	17.72-22.72	17.2-23.02	-17.84-25.52	9.10-24.77	19.10-19.46

Table 3: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for days to 50 per cent flowering, days to maturity and plant height.

SN	Crosses	Days to 50 per cent flowering			Days to maturity			Plant height		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	L1XT1	-0.63	-5.15**	-	6.4**	-	-	28.35**	-	51.66**
2	L2XT1	-0.57	-3.32*	-	-11.7**	-12.8**	-	-7.92**	-	5.39**
3	L3XT1	5.29**	-	-	4.66*	-	-	58.41**	12.68**	73.34**
4	L4XT1	-11.21**	-15.05**	-	-9.76**	-13.37**	-	-30.96**	-	-
5	L5XT1	17.25**	-	-	12.2**	-	-	78.42**	29.64**	85.97**
6	L6XT1	3.17**	-1.6	-	-1.76	-2.13	-	29.37**	-	68.54**
7	L7XT1	8**	-	-	-3.26	-4.99*	-	48.92**	3.62**	72.06**
8	L8XT1	0.59	-5.26**	-	-2.05	-5.21*	-	34.63**	-	60.3**
9	L9XT1	-19.42**	-24.87**	-3.91	-8.77**	-13.66**	-	-19.57**	-	1.41
10	L10XT1	-14.23**	-20.94**	-	-10.81**	-13.74**	-	-1.36	-	-
11	L11XT1	16.22**	-	-	-7.98**	-9.29**	-	106.7**	68.32**	74.09**
12	L12XT1	14.13**	-	-	6.53**	-	-	85.93**	42.18**	74.63**
13	L1XT2	-12.16**	-15.31**	-	11.42**	-	-	-6.81**	-	20.43**
14	L2XT2	11.68**	-	-	14.85**	-	-	-20.85**	-	-
15	L3XT2	4.46**	-	-	8.47**	-2	-	38.32**	8.35**	66.67**
16	L4XT2	2.33*	-1.1	-	5.98**	-4.55*	-	32.52**	2.16**	64.36**
17	L5XT2	12.55**	-	-	17.55**	-	-	-14.26**	-	-
18	L6XT2	11.57**	-	-	20.9**	-	-	21.2**	-	71.32**
19	L7XT2	-1.07	-2.21	-	-10.41**	-17.58**	-2.7	-20.45**	-	0.71
20	L8XT2	2.44*	-2.56*	-	3.17	-6.39**	-	32.3**	-0.54	72.16**
21	L9XT2	1.84	-4.11**	-	0.45	-10.73**	-	18.13**	-	62.04**
22	L10XT2	-5.7**	-12.23**	-	0.81	-8.58**	-	52.08**	43.32**	41.2**
23	L11XT2	20.11**	-	-	22.31**	-	-	105.04**	88.93**	95.4**
24	L12XT2	-9.34**	-13.47**	-2.25	-1.14	-9.69**	-	-3.22**	-	1.61
25	L1XT3	-0.84	-3.38**	-	5.84*	-1.18	-	16.72**	-	61.94**
26	L2XT3	1.62	-	-	9.2**	-	-	24.95**	2.96**	68.72**
27	L3XT3	-5.78**	-7.9**	-	-9**	-17.63**	-	-16.49**	-	8.57**
28	L4XT3	5.26**	-	-	7.82**	-2.72	-	32.67**	10.12**	77.18**
29	L5XT3	0.88	-	-	11.55**	-	-	32.72**	15.48**	65.67**
30	L6XT3	-13.18**	-15.48**	-	-0.59	-7.16**	-	-49.16**	-	-
31	L7XT3	0.74	-	-	10.73**	-	-	21.18**	-	64.95**
32	L8XT3	-1.7	-5.53**	-	4.29	-5.21*	-	16.53**	-	62.72**
33	L9XT3	1.87	-3.1*	-	5.43*	-6.14**	-	18.19**	-	73.38**
34	L10XT3	-19.99**	-24.77**	-1.36	-3.56	-12.39**	-	-1.26	-	1.07
35	L11XT3	18.75**	-	-	20.97**	-	-	84.01**	81.61**	92.86**
36	L12XT3	6.85**	-	-	1.6	-7.01**	-	24.97**	16.51**	43.09**

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis

Table 4: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for no. of primary branches per plant, no. of cluster per plant and no. of mature pods per plant

SN	Crosses	No. of primary branches per plant			No. of cluster per plant			No. of mature pods per plant		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	L1XT1	-14.08**	-	-	-29.29**	-	-	1.45	-	-
2	L2XT1	-22.18**	-	-	7.81**	-	-	-34.68**	-	-
3	L3XT1	-45.81**	-	-	-58.7**	-	-	-52.81**	-	-
4	L4XT1	19.09**	0.88	-	21.29**	-	-	-3.59**	-	-
5	L5XT1	-49.08**	-	-	-33.69**	-	-	-40.43**	-	-
6	L6XT1	-16.7**	-	-	-4.57	-	-	-6.08**	-	-
7	L7XT1	-28.25**	-	-	-48.65**	-	-	-27.76**	-	-
8	L8XT1	-7.23*	-	-	-30.1**	-	-	4.13**	-	-
9	L9XT1	29.98**	-	-	111.1**	65.77**	10.64**	22.4**	-	-
10	L10XT1	11.71**	9.99**	6.16	12.47**	-	-	-6.52**	-	-
11	L11XT1	-48.12**	-	-	-75.6**	-	-	-56.02**	-	-
12	L12XT1	-43.77**	-	-	-71.26**	-	-	-58.48**	-	-
13	L1XT2	-6.13*	-	-	110.88**	53.63**	-	24.02**	-	-
14	L2XT2	21.43**	6.57*	0.1	2.41	-	-	28.38**	8.57**	1.83
15	L3XT2	-22.82**	-	-	-30.47**	-	-	-10.9**	-	-
16	L4XT2	-14.08**	-	-	-1.43	-	-	-16.13**	-	-
17	L5XT2	20.38**	6.03*	-	2.31	-	-	14.25**	13.24**	8.11**
18	L6XT2	-43.83**	-	-	-7.01**	-	-	-21.01**	-	-
19	L7XT2	-15.12**	-	-	32.01**	8.33**	-	-32.14**	-	-
20	L8XT2	-21.77**	-	-	-36.59**	-	-	-19.38**	-	-
21	L9XT2	-15.71**	-	-	-43.56**	-	-	-33.54**	-	-
22	L10XT2	-21.53**	-	-	-13.02**	-	-	-12.41**	-	-
23	L11XT2	-53.55**	-	-	-50.46**	-	-	-39.52**	-	-
24	L12XT2	24.97**	13.83**	-	49.36**	20.44**	8.9**	-0.63	-	-
25	L1XT3	18.04**	9.05*	-	-0.12	-	-	30.82**	26.56**	-
26	L2XT3	-15.14**	-	-	-29.42**	-	-	-5.55**	-	-
27	L3XT3	-12.53**	-	-	18.15**	0.73	-	-20.24**	-	-
28	L4XT3	-25.34**	-	-	-52.66**	-	-	-32.34**	-	-
29	L5XT3	-12.26**	-	-	-25.55**	-	-	-19.82**	-	-
30	L6XT3	59.54**	56.88**	2.15	48.65**	5.1*	-	72.65**	70.97**	-
31	L7XT3	-6.73	-	-	-21.11**	-	-	7.92**	1.92	-
32	L8XT3	20.11**	6.31	-	3.61	-	-	53.78**	37.39**	-
33	L9XT3	-6.52	-	-	-55.59**	-	-	-23.34**	-	-
34	L10XT3	22.07**	3.52	-	86.86**	70.31**	5.11*	32.79**	0.08	3.33
35	L11XT3	-44.84**	-	-	-56.2**	-	-	-22.23**	-	-
36	L12XT3	0.79	-	-	-43.45**	-	-	18.55**	-	-

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis

Table 5: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for pod length, pod diameter and number of seeds per pod.

SN	Crosses	Pod length			Pod diameter			Number of seeds per pod		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	L1XT1	-9.39**	-	-	4.45	-	17.07**	-15.24**	-	-
2	L2XT1	-24.44**	-	-	-2.95	-	7.32	-21.02**	-	-
3	L3XT1	-18.1**	-	-	-8.5**	-	0	-23.15**	-	-
4	L4XT1	-32.43**	-	-	-5.13	-	4.88	-28.66**	-	-
5	L5XT1	6.59*	1.38	-	1.55	1.29	7.32	10.36**	3.49	-
6	L6XT1	13.7**	5.71*	10.56*	3.46	-	12.2*	6.3*	-	2.19
7	L7XT1	-5.33*	-	4.41	15.03**	14.14**	19.51**	-5.53*	-	1.18
8	L8XT1	-4.52	-	-	16.76**	12.85**	19.51**	-7.14*	-	-
9	L9XT1	4.25	2.53	-	2.42	1.52	9.76	0.62	-	-
10	L10XT1	-33.52**	-	-	2.46	1.54	7.32	-40.57**	-	-
11	L11XT1	-7.91**	-	-	-8.91**	-	-	-5.9*	-	-
12	L12XT1	-21.98**	-	-	-10.36**	-	-	-9.19**	-	-
13	L1XT2	75.09**	67.23**	56.61**	0.73	-	12.2*	1.41	-	-
14	L2XT2	14.99**	2.82	11.22*	-4.62	-	4.88	16.94**	5.89*	9.52
15	L3XT2	-18.4**	-	-	10.8**	6.08**	19.51**	-16.81**	-	-
16	L4XT2	26.41**	25.62**	7.07	5.09	-	14.63**	25.07**	22.66**	2.86

17	L5XT2	23.25**	20.23**	2.49	0.66	-	4.88	42.83**	34.78**	13.06**
18	L6XT2	20.78**	9.63**	14.63**	-4.64	-	2.44	-7.96**	-	-
19	L7XT2	-15.47**	-	-	5.67	4.7*	9.76	-29.45**	-	-
20	L8XT2	18**	17.98**	0.58	18.81**	16.76**	19.51**	17.37**	15.59**	0
21	L9XT2	4.31	0	-	13.99**	11.11**	19.51**	18.99**	15.98**	2.44
22	L10XT2	-11.68**	-	-	0.26	-	2.44	-26.06**	-	-
23	L11XT2	4.9	1.84	-	-3.83	-	2.44	-0.82	-	-
24	L12XT2	-3.95	-	-	4.31	-	12.2*	4.48	-	-
25	L1XT3	27.28**	15.13**	7.81	1.43	-	14.63**	14.36**	0.85	3.54
26	L2XT3	43.61**	22.11**	32.09**	-7.19**	-	2.44	42.64**	25.38**	29.65**
27	L3XT3	-19.93**	-	-	-0.87	-	9.76	-22.8**	-	-
28	L4XT3	3.54	-	-	-14.18**	-	-	9.58**	8.04*	-
29	L5XT3	68.39**	62.88**	32.09**	-4.98	-	0	70.48**	66.17**	30.24**
30	L6XT3	-29.27**	-	-	-4.04	-	7.32	-37.43**	-	-
31	L7XT3	30.54**	3.12	34.75**	-5.26	-	0	29.18**	3.81	34.04**
32	L8XT3	31.85**	24.5**	6.15	11.73**	7.07**	14.63**	23.05**	17.28**	1.43
33	L9XT3	-1.31	-	-	-7.07**	-	0	2.17	-	-
34	L10XT3	8.64**	-	-	4.37	2.53	9.76	3.84	-	
35	L11XT3	8.92**	0.04	-	-2.74	-	7.32	3.24	-	-
36	L12XT3	-16.5**	-	-	-4.46	-	4.88	-17.44**	-	-

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis

Table 6: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for 100 seed weight, seed yield per plant and harvest index.

SN	Crosses	100 seed weight			Seed yield per plant			Harvest index		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	L1XT1	12.4**	3.42	8.04	-0.83	-	-	-34.37**	-	-
2	L2XT1	48.69**	46.02**	52.57**	-20.26**	-	-	-18.59**	-	-
3	L3XT1	20.69**	9.03**	13.91*	-45.2**	-	-	-66.62**	-	-
4	L4XT1	42.62**	39.54**	52.39**	16.7**	2.9	-	7.82**	-	-
5	L5XT1	-5.81*	-	-	-41.5**	-	-	-58.58**	-	-
6	L6XT1	7.82*	-	-	-6.78**	-	-	-31.91**	-	-
7	L7XT1	-23.88**	-	-	-28.58**	-	-	-50.81**	-	-
8	L8XT1	2.6	0.34	9.67	-1.77	-	-	-31.12**	-	-
9	L9XT1	-1.01	-	-	42.86**	14.01**	-	87.85**	23.89**	10.6**
10	L10XT1	61.83**	44.04**	50.5**	-0.02	-	-	-17.23**	-	-
11	L11XT1	9.39**	8.1*	12.92*	-50.53**	-	-	-74.27**	-	-
12	L12XT1	12.93**	9.12**	14*	-47.72**	-	-	-65.24**	-	-
13	L1XT2	0.79	-	-	24.22**	-	-	5.69**	-	-
14	L2XT2	-20.71**	-	-	16.4**	2.28	-	29.76**	-	-
15	L3XT2	17.2**	6.25	10.21	-22.19**	-	-	-52.79**	-	-
16	L4XT2	-5.5*	-	0.54	-13.14**	-	-	-36.96**	-	-
17	L5XT2	-19.79**	-	-	8.84**	2.48	-	15.54**	-	-
18	L6XT2	5.1	-	-	-33.78**	-	-	-60.22**	-	-
19	L7XT2	30.21**	19.52**	48.24**	-21.42**	-	-	-26.49**	-	-
20	L8XT2	-18.77**	-	-	-20.82**	-	-	-52.26**	-	-
21	L9XT2	-15.86**	-	-	-23.26**	-	-	-50.99**	-	-
22	L10XT2	6.02	-	-	-13.26**	-	-	-41.01**	-	-
23	L11XT2	-5.55	-	-	-47.32**	-	-	-71.39**	-	-
24	L12XT2	-0.79	-	-	5.12**	4.56*	-	27.01**	7.26**	10.64**
25	L1XT3	-17.67**	-	-	22.58**	11.99**	-	5.18	-	-
26	L2XT3	1.8	-	29**	-2.71	-	-	-11.63**	-	-
27	L3XT3	25.95**	-	49.23**	-12.33**	-	-	-15.75**	-	-
28	L4XT3	-13.34**	-	13.46*	-30.1**	-	-	-43.24**	-	-
29	L5XT3	2.12	-	27.37**	-14.67**	-	-	-23.51**	-	-
30	L6XT3	31.75**	0.02	52.66**	38.89**	37.45**	-	47.78**	35.01**	-
31	L7XT3	-7.4**	-	28.09**	-0.07	-	-	-6.81*	-	-
32	L8XT3	-23.66**	-	0	26.79**	8.58**	-	13.8**	-	-
33	L9XT3	-7.72**	-	15.27*	-15.63**	-	-	-33.85**	-	-
34	L10XT3	-15.25**	-	-	15.9**	-	-	54.96**	21.99**	10.84**
35	L11XT3	-24.81**	-	-	-39.5**	-	-	-63.11**	-	-
36	L12XT3	-22.98**	-	-	4.69*	-	-	-1.97	-	-

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis

Table 7: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for seed length, seed diameter and leaf area index.

SN	Crosses	Seed length			Seed diameter			Leaf area index		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	L1XT1	1.71	1.13	0	6.94*	-	28**	8.52*	-	46.67**
2	L2XT1	33.05**	25.08**	24.64**	-4.08	-	12**	-10.13*	-	21.8*
3	L3XT1	-15.25**	-	-	-16.63**	-	-	-30.47**	-	-
4	L4XT1	-7.43**	-	-	-5.75*	-	8	-25.84**	-	10.64
5	L5XT1	-1.98	-	-	4.27	1.67	8	-27.58**	-	1.99
6	L6XT1	-12.82**	-	-	7.63*	1.48	24**	-28.31**	-	4.21
7	L7XT1	4.27**	-	-	21.87**	19.58**	28**	-23.99**	-	8.81
8	L8XT1	10.41**	2.1	1.45	25.99**	19.17**	28**	24.46**	-	49.58**
9	L9XT1	8.84**	6.63**	5.8	6.17*	4.88	16**	-13.11**	-	15.15
10	L10XT1	-12.7**	-	-	2.94	2.08	8	-12.43**	-	23.77*
11	L11XT1	-18.36**	-	-	-16.73**	-	-	-32.08**	-	-
12	L12XT1	-1.77	-	-	-17.1**	-	-	-32.9**	-	-
13	L1XT2	-24.04**	-	-	3.13	-	16**	5.04	1.2	30.69**
14	L2XT2	16.53**	5.86**	13.04**	-5.67*	-	4	6.89	3.3	33.41**
15	L3XT2	-1.42	-	1.45	22.18**	12.74**	32**	12.09**	10.79*	46.47**
16	L4XT2	-14.4**	-	-	10.98**	-	24**	-16.97**	-	14.95
17	L5XT2	12.7**	6.61**	14.49**	3.8	1.75	4	7.64	6.85	40.04**
18	L6XT2	-9.76**	-	-	-0.82	-	8	-13.09**	-	17
19	L7XT2	30.38**	16.97**	26.09**	10.67**	7.79*	12**	2.86	0.39	36.19**
20	L8XT2	1.93	-	-	34.41**	32.88**	28**	-4.22	-	4.85
21	L9XT2	-3.57*	-	-	27.31**	20.33**	32**	0.71	-	22.65*
22	L10XT2	-15.45**	-	-	1.98	-	4	0.78	-	31.63**
23	L11XT2	-12.17**	-	-	2.29	-	8	-1.36	-	19.38
24	L12XT2	19.18**	0.3	7.25*	7.56*	-	16**	-14.67**	-	12.22
25	L1XT3	-19.45**	-	-	0.37	-	20**	-4.85		19.92
26	L2XT3	-19.15**	-	-	-13.64**	-	0	8.56*	3.68	37.24**
27	L3XT3	13.37**	1.17	24.64**	-3.91	-	8	-0.55	-	31.56**
28	L4XT3	-25.14**	-	-	-22.99**	-		-33.34**	-	-
29	L5XT3	-23.44**	-	-	-6.44*	-	0	-2.79	-	28.05**
30	L6XT3	-19.18**	-	-	-8.4*	-	8	-4.44	-	30.2**
31	L7XT3	-18.52**	-	-	-8.26*	-	0	0.14	-	34.2**
32	L8XT3	-15.02**	-	-	18.2**	-	24**	7.55	-	19.46
33	L9XT3	-21.47**	-	-	-17.03**	-	-	-22.53**	-	-
34	L10XT3	-9.19**	-	8.7**	5.52*	1.98	16**	-12.03**	-	16.32
35	L11XT3	-18.47**	-	-	-5.63*	-	8	-5.87	-	15.44
36	L12XT3	-5.07**	-	-	-10.59**	-	4	-1.15	-	31.57**

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis

Table 8: Estimates of heterosis percent over mid parent, better parent, and standard heterosis for chlorophyll content at 50 per cent flowering and protein content

SN	Crosses	Chlorophyll content at 50 per cent flowering			Protein content		
		MP	BP	SH	MP	BP	SH
1	L1XT1	13.95**	3.16	36.05**	6.65*	0.03	17.7**
2	L2XT1	10.53**	1.5	33.86**	10.24**	4.4	20.31**
3	L3XT1	-16.52**	-	4.52	18.79**	14.87**	18.32**
4	L4XT1	-7.16*	-	22.84**	-6.33*	-	2.72
5	L5XT1	-13.26**	-	9.43	9.98**	9.1**	12.41*
6	L6XT1	-12.9**	-	11.94	12.07**	9.27**	18.48**
7	L7XT1	-9.86**	-	12.53	13.31**	9.9**	20.47**
8	L8XT1	16.31**	-	31**	7.09**	0.6	17.96**
9	L9XT1	-1.97	-	18.89*	-16.16**	-	-
10	L10XT1	-6.06	-	21.33*	-1.39	-	0.37
11	L11XT1	-18.94**	-	3.06	17.59**	11.11**	14.45*
12	L12XT1	-18.95**	-	5.52	15.06**	12.55**	15.97**
13	L1XT2	24.73**	17.51**	25.63**	-8.31**	-	-3.56
14	L2XT2	23.4**	14.57**	26.4**	0.19	-	4.19
15	L3XT2	27.05**	14.18**	35.37**	25**	22.76**	18.12**
16	L4XT2	-1.99	-	11.4	13.05**	1.61	18.17**

17	L5XT2	15.55**	3.12	24.21**	4.97	0.52	1.88
18	L6XT2	-1.13	-	8.6	13.1**	4.93	13.77*
19	L7XT2	20.17**	8.32*	27.58**	19.01**	9.86**	20.42**
20	L8XT2	16.08**	15.37**	9.06	10.81**	-	16.39**
21	L9XT2	5.12	-	7.86	16.55**	5.65	20.52**
22	L10XT2	9.52*	-	20.98*	4.78	0.71	1.31
23	L11XT2	-0.33	-	8.1	25.52**	24.77**	15.76**
24	L12XT2	5.88	-	18.08*	-5.84	-	-
25	L1XT3	-7.08*	-	10.52	-2.27	-	15.6**
26	L2XT3	-3.68	-	16.2	-8.42**	-	7.23
27	L3XT3	3.54	-	29.19**	10.31**	-	18.69**
28	L4XT3	-21.62**	-	3.36	0.47	-0.65	18.17**
29	L5XT3	-7.44*	-	16.38	-2.42	-	7.49
30	L6XT3	-6.25	-	20.04*	-14.82**	-	-
31	L7XT3	-5.36	-	17.71*	-6.48*	-	6.86
32	L8XT3	-1.39	-	10.61	-0.89	-	17.02**
33	L9XT3	-13.8**	-	4.17	-0.67	-	15.76**
34	L10XT3	-7.2*	-	19.43*	-17.84**	-	-
35	L11XT3	-13.62**	-	9.43	8.98**	-	14.76*
36	L12XT3	-7.88*	-	19.52*	-8.58**	-	-

*, ** Significant at 5% and 1%, respectively, MP Heterosis, BP Heterobeltiosis, SH Economic heterosis.

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