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HALF DIALLEL ANALYSIS OF COMBINING ABILITY AND HETEROTIC POTENTIAL FOR GROWTH, YIELD ATTRIBUTING AND QUALITY CHARACTERS IN BRINJAL (*Solanum melongena* L.)

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ABSTRACT

A study was conducted to assess the general and specific combining ability and the magnitude of heterosis for growth, yield-attributing and quality traits in brinjal (*Solanum melongena* L.). Eight genetically diverse round-fruited genotypes, namely Thar Rachita, Pusa Bindu, Kashi Uttam, Ajad Brinjal-1, KS-445, RCB-22, GNRB-1 and Swarna Shyamli, were crossed in a half diallel fashion, excluding reciprocals, to generate twenty-eight F₁ hybrids. The parents, hybrids and the standard commercial check Pusa Hybrid-6 were evaluated in a randomized block design with three replications at Vegetable Research Farm, Rajasthan Agricultural Research Institute, Durgapura, Jaipur, during Kharif 2025. Observations were recorded for plant height, leaf area, number of fruits per cluster, phenol content, total soluble solids and chlorophyll content. Analysis of variance revealed highly significant differences among the genotypes for all the traits studied, confirming adequate genetic variability for further genetic analysis. Combining ability analysis, carried out following Griffing's Method II, Model I, showed that both the general combining ability and the specific combining ability variances were highly significant for all six traits, indicating the involvement of both additive and non-additive gene action; plant height, leaf area and chlorophyll content were governed predominantly by additive gene action, whereas number of fruits per cluster, phenol content and total soluble solids were governed predominantly by non-additive gene action. Among the parents, Pusa Bindu, Ajad Brinjal-1, Kashi Uttam and GNRB-1 emerged as the best general combiners for one or more of the traits studied. The cross Ajad Brinjal-1 × Swarna Shyamli recorded significant and desirable specific combining ability effects and heterosis for plant height, leaf area, phenol content and chlorophyll content, while Thar Rachita × Pusa Bindu was outstanding for plant height and number of fruits per cluster, and Pusa Bindu × KS-445 and Kashi Uttam × GNRB-1 were promising for number of fruits per cluster and phenol content, respectively. Heterosis over the mid parent, better parent and standard check varied widely across crosses and traits, with several hybrids exhibiting significant positive heterosis of appreciable magnitude, particularly for number of fruits per cluster and leaf area. The results suggest that traits governed by additive gene action may be improved through simple selection, while traits under non-additive control offer good scope for exploitation of heterosis. The promising cross combinations identified in the present study merit further evaluation across locations before being advanced for commercial hybrid development in brinjal.

Key words: Brinjal, Half diallel, Combining ability, Heterosis, Gene action

Introduction

Brinjal or eggplant (*Solanum melongena* L.), a member of the family Solanaceae, ranks among the most widely grown and economically important vegetable crops of the tropical and sub-tropical world, occupying the third position among solanaceous vegetables after tomato and potato in terms of global production (FAOSTAT, 2024). In India, the crop occupies a place of pride in the daily diet of millions of households on account of its low cost, year-round availability and adaptability to diverse agro-climatic conditions. Rajasthan, though not traditionally regarded as a major brinjal-growing state, has been witnessing a steady expansion in area under this crop owing to its tolerance to heat and moisture stress, which makes it well suited to the semi-arid tracts of the state. Besides its culinary value, brinjal fruit is a rich source of phenolic compounds, ascorbic acid and other antioxidant principles, and possesses recognised nutraceutical and folk-medicinal value (Saha *et al.*, 2023).

Despite its wide adaptability and dietary importance, the productivity of brinjal in India continues to lag behind its potential, not only because of improper nutrition (Choudhary *et al.*, 2025) and weed management (Choudhary *et al.*, 2026) but also because commercial cultivation still relies on a comparatively narrow genetic base and the available varieties seldom combine all the desirable growth, yield and quality attributes in a single genotype (Jeetarwal *et al.*, 2026). Exploitation of hybrid vigour offers one of the most rewarding avenues for overcoming this constraint and brinjal, being amenable to hand emasculatation and pollination and bearing a large number of seeds per fruit, is particularly well suited to commercial hybrid seed production. Since the early reports of hybrid vigour in this crop, a large body of evidence has accumulated on the heterotic potential of brinjal for fruit yield and its component traits.

The success of a heterosis breeding programme, however, depends entirely on the judicious choice of parents, which in turn calls for a clear understanding of the nature and magnitude of gene action governing the traits under improvement. The concept of general combining ability (GCA), which reflects the average performance of a parent in a series of crosses and is largely a function of additive gene effects, and specific combining ability (SCA), which reflects the deviation of a particular cross from the performance expected on the basis of the general combining ability of its parents and is largely attributable to non-additive (dominance and epistatic) gene effects, together provide the breeder with the information needed to identify superior parents as well as promising cross combinations (Griffing, 1956).

Parents with high general combining ability are useful in pure-line breeding and as components of synthetic populations, whereas crosses with high specific combining ability, particularly those combining genetically diverse parents, hold promise for direct commercial exploitation of heterosis.

While a number of workers have reported on combining ability and heterosis for fruit yield and its components in brinjal, comparatively little information is available on the joint genetic analysis of vegetative, yield-attributing and biochemical quality traits such as leaf area, number of fruits per cluster, phenol content, total soluble solids and chlorophyll content in a common set of genetic material, particularly under the semi-arid agro-climatic conditions of eastern Rajasthan. Keeping these facts in view, the present investigation was undertaken to estimate the general and specific combining ability effects, to work out the magnitude and direction of heterosis over the mid parent, better parent and standard check, and to identify superior parents and promising cross combinations for growth, yield-attributing and quality traits in brinjal, so as to provide a sound genetic basis for future hybrid breeding programmes in this crop.

Materials and Methods

Experimental site and season

The present investigation was carried out at the Vegetable Research Farm, Rajasthan Agricultural Research Institute (SKN Agriculture University), Durgapura, Jaipur, during the *Kharif* season of 2025. The experimental site, situated at 26.5°N latitude and 75.47°E longitude at an elevation of 390 m above mean sea level, falls under the semi-arid Agro-Climatic Zone III-A (Semi-Arid Eastern Plain) of Rajasthan, characterized by hot, dry summers and mild winters; the mean maximum and minimum temperatures during the crop season ranged from 24.0–35.3°C and 7.6–24.0°C, respectively, with relative humidity varying between 71.6 and 92.4 per cent.

Plant material and mating design

The experimental material comprised eight genetically diverse, round-fruited brinjal genotypes, viz., Thar Rachita, Pusa Bindu, Kashi Uttam, Ajad Brinjal-1, KS-445, RCBR-22, GNRB-1 and Swarna Shyamli, procured from different ICAR institutes and State Agricultural Universities and selected on the basis of variation in morphological, geographic and quantitative attributes. During Kharif 2024, the eight parents were inter-mated in a half diallel fashion, excluding reciprocals, to generate twenty-eight F_1 combinations, following hand emasculatation of the female parent in the evening and

Table 1: Analysis of variance for parent's vs F_1 hybrids for growth, yield attributing and quality traits in brinjal.

Source of variation	df.	PH	LA	NFPCL	PC	TSS	CC
Replication	2	26.977	84.778	0.017	190.780	0.019	8.144
Treatment	36	252.713**	609.754**	1.597**	4511.110**	0.883**	33.100**
Parents	7	362.764**	719.063**	1.683**	7386.620**	1.458**	63.788**
F_1 's	27	242.834**	596.498**	1.640**	3854.090**	0.782**	26.085**
Parents vs F_1 's	1	1.209	739.103**	0.274**	205.920	0.065*	40.526**
Check vs F_1 's	1	0.438	118.780	1.245**	6179.080**	0.391**	0.003
Error	72	28.368	39.490	0.039	117.870	0.016	4.629

PH = Plant height at harvest (cm); LA = Leaf area (cm²); NFPCL = Number of fruits per cluster;
PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units).
*, ** = significant at 5% and 1% probability levels, respectively.

pollination the following morning with freshly collected pollen from the male parent. In Kharif 2025, the eight parents, the twenty-eight F_1 hybrids and the commercial hybrid check 'Pusa Hybrid-6' (thirty-seven entries in all) were evaluated in a randomized block design with three replications, each entry being accommodated in a single row with 60 cm row-to-row and 60 cm plant-to-plant spacing. Seeds were sown in pro-trays on 15 July 2025 and thirty-five-day-old seedlings were transplanted on 21 August 2025, following recommended agronomic and plant protection practices.

Observations recorded

Data were recorded on five randomly selected and tagged plants in each replication for plant height at harvest (cm), leaf area (cm², using a CI-203 laser leaf area meter), number of fruits per cluster, total soluble solids (°Brix, using a hand refractometer) and chlorophyll content (SPAD units, using a SPAD-502Plus chlorophyll meter). Phenol content (mg/100 g) of the fruit was estimated colorimetrically at 650 nm using the Folin-Ciocalteu method with catechol as the standard, and the mean of the five plants was used for statistical analysis.

Statistical analysis

The data were subjected to analysis of variance as per the standard procedure for a randomized block design (Panse and Sukhatme, 2000) to test the significance of

differences among the parents, hybrids and the standard check, including the orthogonal contrasts of parents versus hybrids and check versus hybrids. Combining ability analysis was carried out following Method II, Model I of Griffing (1956), which considers the parents together with their one-way set of F_1 crosses, excluding reciprocals; the general combining ability (GCA) effects of the parents and the specific combining ability (SCA) effects of the crosses were estimated along with their standard errors and tested for significance by 't' test. The relative magnitude of additive and non-additive gene action governing each trait was assessed from the ratio of GCA to SCA variance ($\sigma^2_{gca}/\sigma^2_{sca}$). Heterosis was estimated as the percentage increase or decrease of the F_1 hybrid mean over the mid-parent value (relative heterosis), the better-parent value (heterobeltiosis), and the standard check 'Pusa Hybrid-6' (standard heterosis), following the method of Fonseca and Patterson (1968), and the significance of the heterotic effects was tested by 't' test at the error degrees of freedom, following Snedecor and Cochran (1989).

Results and Discussion

Analysis of variance

Analysis of variance for the randomized block design (Table 1) revealed highly significant mean squares due to treatments (parents + hybrids) for all six traits studied, viz., plant height, leaf area, number of fruits per cluster,

Table 2: Analysis of variance for combining ability and estimates of GCA/SCA variance ratio and gene action for growth, yield attributing and quality traits in brinjal.

Source of variation	df.	PH	LA	NFPCL	PC	TSS	CC
GCA	7	214.381**	705.787**	2.034**	6472.712**	1.107**	28.477**
SCA	28	54.703**	84.006**	0.162**	238.643**	0.097**	7.063**
Error	72	9.134	13.066	0.013	38.344	0.004	1.527
$\sigma^2_{gca}/\sigma^2_{sca}$		0.450	0.976	1.356	3.260	1.180	0.487
Gene action		Additive	Additive	Non-additive	Non-additive	Non-additive	Additive

PH = Plant height at harvest (cm); LA = Leaf area (cm²); NFPCL = Number of fruits per cluster;
PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units).
*, ** = significant at 5% and 1% probability levels, respectively.

Table 3: Mean (per se) performance of parents, F_1 hybrids and standard check for growth, yield attributing and quality traits in brinjal.

Genotypes	Type	PH	LA	NFPCL	PC	TSS	CC
Thar Rachita	Parent	64.13	62.33	2.40	276.90	4.40	56.59
Pusa Bindu	Parent	77.00	81.47	2.19	287.92	4.91	54.68
Kashi Uttam	Parent	70.53	82.34	1.00	347.13	3.94	48.25
Ajad Brinjal-1	Parent	68.50	96.94	2.68	307.16	4.10	49.81
KS-445	Parent	74.20	93.73	1.00	270.00	4.00	44.90
RCBR-22	Parent	53.43	69.01	1.00	223.96	3.63	44.92
GNRB-1	Parent	76.73	83.61	1.00	321.87	5.30	55.50
Swarna Shyamli	Parent	47.12	51.85	1.00	196.73	3.10	49.38
Pusa Hybrid-6	Check	67.10	77.55	1.00	328.47	4.60	49.06
TR $\times$ PB	F_1	85.09	80.88	2.78	293.27	4.60	51.22
TR $\times$ KU	F_1	56.63	75.88	2.30	297.97	4.08	50.06
TR $\times$ A.B1	F_1	63.43	72.33	2.13	281.37	3.99	50.97
TR $\times$ KS-445	F_1	63.33	91.89	2.20	268.60	3.80	52.40
TR $\times$ RCBR-22	F_1	45.49	75.90	2.37	243.23	4.47	52.58
TR $\times$ GNRB-1	F_1	70.50	80.19	2.10	323.87	5.10	55.06
TR $\times$ S.S	F_1	66.45	58.02	2.77	218.30	4.07	49.52
PB $\times$ KU	F_1	72.46	81.59	2.23	327.97	4.09	49.56
PB $\times$ A.B1	F_1	76.62	102.84	2.90	293.80	4.80	49.51
PB $\times$ KS-445	F_1	75.08	103.04	2.62	263.84	4.26	46.45
PB $\times$ RCBR-22	F_1	55.98	74.89	2.19	242.33	3.40	47.19
PB $\times$ GNRB-1	F_1	76.69	77.66	2.46	337.95	5.21	51.52
PB $\times$ S.S	F_1	62.47	60.34	2.29	281.60	4.29	44.66
KU $\times$ A.B1	F_1	72.23	98.39	1.00	318.73	4.30	48.42
KU $\times$ KS-445	F_1	67.66	103.75	1.00	291.53	3.59	46.71
KU $\times$ RCBR-22	F_1	58.22	103.72	1.00	284.29	4.20	51.32
KU $\times$ GNRB-1	F_1	58.00	83.85	1.00	356.53	4.61	52.09
KU $\times$ S.S	F_1	58.36	65.71	1.00	302.90	3.82	47.15
A.B1 $\times$ KS-445	F_1	60.11	91.60	1.00	292.93	3.90	49.21
A.B1 $\times$ RCBR-22	F_1	75.52	81.59	1.00	283.50	4.50	45.93
A.B1 $\times$ GNRB-1	F_1	76.67	104.25	1.00	312.81	4.90	46.97
A.B1 $\times$ S.S	F_1	73.60	96.52	1.00	288.97	3.70	55.78
KS-445 $\times$ RCBR-22	F_1	73.50	88.85	1.00	247.44	3.64	46.24
KS-445 $\times$ GNRB-1	F_1	77.31	101.33	1.00	285.65	5.10	46.51
KS-445 $\times$ S.S	F_1	56.40	64.85	1.00	220.00	3.29	47.31
RCBR-22 $\times$ GNRB-1	F_1	64.41	86.39	1.00	264.77	4.30	47.29
RCBR-22 $\times$ S.S	F_1	60.75	73.98	1.00	207.69	3.97	44.70
GNRB-1 $\times$ S.S	F_1	64.95	70.38	1.00	272.00	4.53	46.47
PH = Plant height at harvest (cm); LA = Leaf area (cm ²); NFPCL = Number of fruits per cluster; PC = Phenol content (mg/100 g); TSS = Total soluble solids ($^{\circ}$ Brix); CC = Chlorophyll content (SPAD units). *, ** = significant at 5% and 1% probability levels, respectively.							

phenol content, total soluble solids and chlorophyll content, indicating the presence of substantial genetic variability among the genotypes and justifying further genetic analysis. The mean squares due to parents alone and due to hybrids alone were also highly significant for all the traits, confirming that variability existed both among the parental lines and among their F_1 combinations. The contrast of parents versus hybrids was significant for leaf area, number of fruits per cluster and chlorophyll

content but non-significant for plant height, phenol content and total soluble solids, suggesting an overall heterotic departure of the F_1 population from the general parental mean for the former group of traits. Likewise, the contrast of the standard check 'Pusa Hybrid-6' versus the hybrids was significant for number of fruits per cluster, phenol content and total soluble solids, but non-significant for plant height, leaf area and chlorophyll content, indicating that the hybrid population as a whole differed appreciably

Table 4: Estimates of general combining ability (gca) effects of parents for growth, yield attributing and quality traits in brinjal.

Parent	PH	LA	NFPCL	PC	TSS	CC
Thar Rachita	-2.069*	-8.323**	0.680**	-5.348**	0.093**	3.078**
Pusa Bindu	5.848**	0.120	0.721**	8.272**	0.250**	0.527
Kashi Uttam	-1.526	3.460**	-0.312**	34.031**	-0.140**	-0.239
Ajad Brinjal-1	3.529**	9.843**	0.074*	15.255**	0.032	0.220
KS-445	2.189*	8.981**	-0.283**	-12.387**	-0.235**	-1.958**
RCBR-22	-5.915**	-1.962	-0.309**	-31.271**	-0.223**	-1.912**
GNRB-1	4.210**	2.828*	-0.310**	26.343**	0.638**	1.269**
Swarna Shyamli	-6.267**	-14.946**	-0.260**	-34.895**	-0.411**	-0.985**
S.E.±	0.894	1.069	0.034	1.832	0.019	0.366
C.D. 5%	2.52	3.01	0.10	5.16	0.05	1.03
C.D. 1%	3.35	4.00	0.13	6.85	0.07	1.37
PH = Plant height at harvest (cm); LA = Leaf area (cm ²); NFPCL = Number of fruits per cluster; PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units). *, ** = significant at 5% and 1% probability levels, respectively.						

from the commercial check specifically for these three traits.

Combining ability analysis and gene action

The analysis of variance for combining ability (Table 2) revealed that the mean squares due to general combining ability (GCA) as well as specific combining ability (SCA) were highly significant ($p < 0.01$) for all six characters, indicating that both additive and non-additive components of genetic variance were operating in the inheritance of these traits, a finding in conformity with the reports of several earlier workers in brinjal (Chowdhury *et al.*, 2010; Kumar *et al.*, 2012; Makani *et al.*, 2013). The relative predominance of the two types of gene action was assessed from the ratio of GCA to SCA variance ($\sigma^2_{gca}/\sigma^2_{sca}$), which worked out to 0.450, 0.976, 1.356, 3.26, 1.18 and 0.487 for plant height, leaf area, number of fruits per cluster, phenol content, total soluble solids and chlorophyll content, respectively (Table 2). On this basis, plant height, leaf area and chlorophyll content were classified as being governed predominantly by additive gene action, while number of fruits per cluster, phenol content and total soluble solids showed a predominance of non-additive gene action. These findings suggest that a two-pronged breeding strategy would be most rewarding in the present material: simple selection in early segregating generations for plant height, leaf area and chlorophyll content, coupled with exploitation of heterosis through hybridisation for number of fruits per cluster, phenol content and total soluble solids (Anvesh *et al.*, 2024).

Mean (per se) performance

The mean performance of the parents and hybrids (Table 3) revealed a wide range of variation for all the traits studied. Among the parents, Pusa Bindu recorded

the maximum plant height (77.00 cm) followed by GNRB-1 (76.73 cm), while Swarna Shyamli was the shortest (47.12 cm). Ajad Brinjal-1 recorded the maximum leaf area (96.94 cm²) and the highest number of fruits per cluster (2.68), Kashi Uttam the highest phenol content (347.13 mg/100 g), GNRB-1 the highest total soluble solids (5.30 °Brix), and Thar Rachita the highest chlorophyll content (56.59 SPAD units); Swarna Shyamli was the poorest performer for most of the traits, recording the lowest leaf area, phenol content and total soluble solids among the parents. Among the hybrids, Thar Rachita × Pusa Bindu recorded the highest plant height (85.09 cm), Ajad Brinjal-1 × GNRB-1 the highest leaf area (104.25 cm²), Pusa Bindu × Ajad Brinjal-1 the highest number of fruits per cluster (2.90), Kashi Uttam × GNRB-1 the highest phenol content (356.53 mg/100 g), Pusa Bindu × GNRB-1 the highest total soluble solids (5.21 °Brix), and Ajad Brinjal-1 × Swarna Shyamli the highest chlorophyll content (55.78 SPAD units); several of these hybrids also exceeded the standard check 'Pusa Hybrid-6' for the respective traits.

General combining ability effects

The estimates of general combining ability effects of the eight parents (Table 4) revealed that no single parent was a good general combiner for all the traits studied, which is not unexpected in view of the diverse genetic background of the material used. Pusa Bindu was the best general combiner for plant height (5.848) and number of fruits per cluster (0.721), Ajad Brinjal-1 for leaf area (9.843), Kashi Uttam for phenol content (34.031), GNRB-1 for total soluble solids (0.638), and Thar Rachita for chlorophyll content (3.078); all these estimates were significant at the 1 per cent level. GNRB-1 was also a good general combiner for phenol content (26.343)

Table 5: Estimates of specific combining ability (sca) effects of F₁ hybrids for growth, yield attributing and quality traits in brinjal.

Cross combination	PH	LA	NFPCL	PC	TSS	CC
TR × PB	14.651**	6.531	-0.250*	8.806	0.036	-1.742
TR × KU	-6.425*	-1.812	0.304**	-12.250*	-0.090	-2.132
TR × A.B1	-4.681	-11.738**	-0.249*	-10.082	-0.354**	-1.684
TR × KS-445	-3.441	8.680**	0.177	4.793	-0.273**	1.925
TR × RCBR-22	-13.176**	3.633	0.374**	-1.689	0.377**	2.058
TR × GNRB-1	1.704	3.129	0.101	21.330**	0.150*	1.356
TR × S.S	8.133**	-1.265	0.719**	-22.998**	0.165**	-1.929
PB × KU	1.479	-4.541	0.196	4.121	-0.240**	-0.085
PB × A.B1	0.590	10.322**	0.477**	-11.270*	0.298**	-0.591
PB × KS-445	0.389	11.384**	0.556**	-13.584*	0.027	-1.472
PB × RCBR-22	-10.609**	-5.819	0.154	-16.217**	-0.846**	-0.782
PB × GNRB-1	-0.026	-7.843*	0.421**	21.791**	0.103	0.366
PB × S.S	-3.769	-7.385*	0.201	26.681**	0.235**	-4.238**
KU × A.B1	3.575	2.538	-0.390**	-12.095*	0.188**	-0.918
KU × KS-445	0.341	8.757**	-0.033	-11.653*	-0.247**	-0.452
KU × RCBR-22	-0.993	19.673**	-0.007	-0.009	0.346**	4.111**
KU × GNRB-1	-11.338**	-4.993	-0.007	14.617*	-0.105	1.706
KU × S.S	-0.501	-5.352	-0.056	22.222**	0.153**	-0.979
A.B1 × KS-445	-12.266**	-9.772**	-0.419**	8.523	-0.112	1.589
A.B1 × RCBR-22	11.251**	-8.842**	-0.394**	17.974**	0.472**	-1.731
A.B1 × GNRB-1	2.272	9.023**	-0.393**	-10.334	0.011	-3.873**
A.B1 × S.S	9.683**	19.071**	-0.443**	27.065**	-0.141*	7.189**
KS-445 × RCBR-22	10.570**	-0.717	-0.036	9.561	-0.116*	0.755
KS-445 × GNRB-1	4.252	6.968*	-0.036	-9.845	0.483**	-2.161
KS-445 × S.S	-6.177*	-11.736**	-0.085	-14.259*	-0.283**	0.901
RCBR-22 × GNRB-1	-0.536	2.975	-0.010	-11.846*	-0.334**	-1.427
RCBR-22 × S.S	6.274*	8.340*	-0.060	-7.687	0.381**	-1.759
GNRB-1 × S.S	0.355	-0.054	-0.059	-0.989	0.084	-3.167**
S.E.±	2.740	3.278	0.104	5.610	0.057	1.121
C.D. 5%	7.73	9.34	0.29	15.83	0.16	3.16
C.D. 1%	10.25	12.26	0.39	21.01	0.21	4.19
PH = Plant height at harvest (cm); LA = Leaf area (cm ²); NFPCL = Number of fruits per cluster; PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units). *, ** = significant at 5% and 1% probability levels, respectively.						

besides total soluble solids, while Ajad Brinjal-1 combined good general combining ability for leaf area with a significant positive effect for phenol content (15.255) as well. Swarna Shyamli, on the other hand, recorded significant negative general combining ability effects for practically every trait studied and consequently emerged as the poorest general combiner in the set. Parents exhibiting high general combining ability for a particular trait are believed to carry a preponderance of additive gene effects and hence a large number of desirable fixable genes for that trait (Kumar *et al.*, 2012); such parents can therefore be profitably used either for further recombination breeding or as components of synthetic/composite populations aimed at improvement of the respective traits (Akhtar *et al.*, 2019).

Specific combining ability effects

As regards specific combining ability, the cross Ajad Brinjal-1 × Swarna Shyamli recorded significant and desirable specific combining ability effects for as many as four of the six traits studied, viz., plant height (9.683), leaf area (19.071), phenol content (27.065) and chlorophyll content (7.189), and was thus identified as the most outstanding specific combiner in the present study, notwithstanding the fact that neither Ajad Brinjal-1 nor Swarna Shyamli was among the best general combiners for most of these traits. This finding is in conformity with the well-documented observation that crosses involving parents with divergent, and even poor, general combining ability may still show high specific combining ability owing

Table 6: Estimates of relative heterosis (heterosis over mid parent, %) for growth, yield attributing and quality traits in brinjal.

Cross combination	PH	LA	NFPCL	PC	TSS	CC
TR × PB	20.57**	12.49*	21.02**	3.85	-1.25	-7.94**
TR × KU	-15.89**	4.90	35.29**	-4.50	-2.06	-4.50
TR × A.B1	-4.35	-9.17	-16.04**	-3.65	-6.13**	-4.19
TR × KS-445	-8.43	17.76**	29.50**	-1.77	-9.52**	3.27
TR × RCBR-22	-22.61**	15.58*	39.58**	-2.87	11.20**	3.60
TR × GNRB-1	0.09	9.89	23.53**	8.18**	5.15**	-1.75
TR × S.S	19.46**	1.63	62.75**	-7.82*	8.44**	-6.53*
PB × KU	-1.78	-0.38	39.92**	3.29	-7.57**	-3.71
PB × A.B1	5.32	15.29**	18.99**	-1.26	6.48**	-5.23
PB × KS-445	-0.68	17.62**	64.30**	-5.42	-4.48*	-6.70*
PB × RCBR-22	-14.16*	-0.46	37.51**	-5.32	-20.43**	-5.24
PB × GNRB-1	-0.23	-5.91	54.19**	10.84**	2.03	-6.48*
PB × S.S	0.66	-9.48	43.47**	16.21**	7.15**	-14.16**
KU × A.B1	3.91	9.77	-45.68**	-2.57	6.95**	-1.24
KU × KS-445	-6.50	17.85**	0.00	-5.52*	-9.47**	0.28
KU × RCBR-22	-6.07	37.07**	0.00	-0.44	11.02**	10.15**
KU × GNRB-1	-21.23**	1.05	0.00	6.59**	-0.12	0.42
KU × S.S	-0.79	-2.06	0.00	11.39**	8.61**	-3.40
A.B1 × KS-445	-15.76**	-3.91	-45.68**	1.51	-3.74	3.92
A.B1 × RCBR-22	23.87**	-1.67	-45.68**	6.76*	16.34**	-3.02
A.B1 × GNRB-1	5.58	15.48**	-45.68**	-0.54	4.23*	-10.78**
A.B1 × S.S	27.31**	29.74**	-45.68**	14.69**	2.73	12.48**
KS-445 × RCBR-22	15.17*	9.20	0.00	0.19	-4.63	2.97
KS-445 × GNRB-1	2.44	14.28**	0.00	-3.47	9.68**	-7.35*
KS-445 × S.S	-7.02	-10.91	0.00	-5.73	-7.45**	0.37
RCBR-22 × GNRB-1	-1.03	13.22*	0.00	-2.98	-3.73	-5.82
RCBR-22 × S.S	20.83**	22.43**	0.00	-1.26	17.81**	-5.19
GNRB-1 × S.S	4.89	3.92	0.00	4.90	7.85**	-11.37**

PH = Plant height at harvest (cm); LA = Leaf area (cm²); NFPCL = Number of fruits per cluster;
PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units).
*, ** = significant at 5% and 1% probability levels, respectively.

to complementary dominance and epistatic gene interaction between the parents (Sarsar *et al.*, 1986; Makani *et al.*, 2013). Other promising specific combinations included Thar Rachita × Pusa Bindu, which combined two relatively good general combiners for plant height and recorded the highest positive sca effect for this trait (14.651); Kashi Uttam × RCBR-22 for leaf area (19.673) and chlorophyll content (4.111); Pusa Bindu × KS-445 for number of fruits per cluster (0.556); and KS-445 × GNRB-1 for total soluble solids (0.483), which combined two parents both possessing favourable general combining ability for this trait. The occurrence of high sca effects in crosses involving at least one good general combiner, as observed for Thar Rachita × Pusa Bindu and KS-445 × GNRB-1, points to the operation of additive × dominance type gene interaction, whereas the superior performance of Ajad Brinjal-1 × Swarna Shyamli despite the poor general combining ability of its parents is

suggestive of dominance × dominance (epistatic) interaction (Rawlings and Thompson, 1962).

Heterosis

The estimates of heterosis over the mid parent (relative heterosis), the better parent (heterobeltiosis) and the standard check 'Pusa Hybrid-6' (standard heterosis) for the six traits are presented in Tables 6, 7 and 8, respectively. Significant positive relative heterosis was recorded by a fairly large number of crosses for leaf area, number of fruits per cluster and total soluble solids (twelve, twelve and thirteen crosses, respectively), whereas comparatively fewer crosses showed significant positive relative heterosis for plant height (six), phenol content (seven) and chlorophyll content (two crosses only), reflecting a relatively narrower scope for the exploitation of hybrid vigour for the latter trait in the present material.

Heterobeltiosis followed a broadly similar but more

Table 7: Estimates of heterobeltiosis (heterosis over better parent, %) for growth, yield attributing and quality traits in brinjal.

Cross combination	PH	LA	NFPCL	PC	TSS	CC
TR × PB	10.50	-0.72	15.79*	1.86	-6.40**	-9.48**
TR × KU	-19.71**	-7.85	-4.17	-14.16**	-7.20**	-11.53**
TR × A.B1	-7.40	-25.38**	-20.46**	-8.40**	-9.30**	-9.93**
TR × KS-445	-14.65*	-1.97	-8.27	-3.00	-13.64**	-7.40*
TR × RCBR-22	-29.06**	9.99	-1.13	-12.16**	1.52	-7.08*
TR × GNRB-1	-8.12	-4.09	-12.50	0.62	-3.77	-2.70
TR × S.S	3.61	-6.92	15.28*	-21.16**	-7.58**	-12.49**
PB × KU	-5.90	-0.91	1.87	-5.52*	-16.74**	-9.37**
PB × A.B1	-0.49	6.09	8.13	-4.35	-2.30	-9.45**
PB × KS-445	-2.49	9.93	19.62**	-8.36**	-13.36**	-15.05**
PB × RCBR-22	-27.30**	-8.07	0.12	-15.84**	-30.80**	-13.70**
PB × GNRB-1	-0.41	-7.12	12.26	5.00	-1.70	-7.17*
PB × S.S	-18.87**	-25.93**	4.46	-2.20	-12.61**	-18.33**
KU × A.B1	2.41	1.50	-62.71**	-8.18**	4.81	-2.78
KU × KS-445	-8.81	10.69	0.00	-16.02**	-10.17**	-3.21
KU × RCBR-22	-17.46**	25.97**	0.00	-18.10**	6.72*	6.35
KU × GNRB-1	-24.41**	0.29	0.00	2.71	-12.96**	-6.13
KU × S.S	-17.26**	-20.19**	0.00	-12.74**	-2.94	-4.50
A.B1 × KS-445	-18.99**	-5.50	-62.71**	-4.63	-4.94	-1.20
A.B1 × RCBR-22	10.25	-15.83**	-62.71**	-7.70**	9.68**	-7.78*
A.B1 × GNRB-1	-0.09	7.54	-62.71**	-2.82	-7.55**	-15.36**
A.B1 × S.S	7.45	-0.43	-62.71**	-5.92*	-9.82**	11.99**
KS-445 × RCBR-22	-0.94	-5.21	0.00	-8.35*	-9.00**	2.94
KS-445 × GNRB-1	0.75	8.10	0.00	-11.25**	-3.77	-16.20**
KS-445 × S.S	-23.99**	-30.81**	0.00	-18.52**	-17.86**	-4.18
RCBR-22 × GNRB-1	-16.06**	3.33	0.00	-17.74**	-18.87**	-14.79**
RCBR-22 × S.S	13.69	7.21	0.00	-7.26	9.17**	-9.47**
GNRB-1 × S.S	-15.35**	1.26	-15.82*	-15.49**	-14.53**	-16.26**

PH = Plant height at harvest (cm); LA = Leaf area (cm²); NFPCL = Number of fruits per cluster;
PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units).
*, ** = significant at 5% and 1% probability levels, respectively.

restricted trend. Not a single cross recorded significant positive heterobeltiosis for plant height or phenol content, indicating that none of the hybrids could significantly surpass its respective better parent for these two traits, even though several crosses exceeded the mid-parent value; this is consistent with the already high per se performance of parents such as Pusa Bindu and Kashi Uttam, which left comparatively little room for further improvement through heterosis. In contrast, Kashi Uttam × RCBR-22 exhibited significant positive heterobeltiosis for leaf area (25.97%), Pusa Bindu × KS-445 for number of fruits per cluster (19.62%), and Ajad Brinjal-1 × RCBR-22 for total soluble solids (9.68%); Ajad Brinjal-1 × Swarna Shyamli was the sole hybrid to record significant positive heterobeltiosis for chlorophyll content (11.99%).

Over the standard check, the cross Pusa Bindu × Ajad Brinjal-1 recorded the maximum standard heterosis for number of fruits per cluster (190.00%), followed

closely by Thar Rachita × Pusa Bindu (177.89%) and Thar Rachita × Swarna Shyamli (176.67%), reflecting a spectacular improvement over the commercial hybrid check for this yield-attributing trait. Ajad Brinjal-1 × GNRB-1 (34.43%), Kashi Uttam × KS-445 (33.79%) and Kashi Uttam × RCBR-22 (33.76%) were the most heterotic crosses over the check for leaf area, while Kashi Uttam × GNRB-1 (8.54%) was the only cross to record significant positive standard heterosis for phenol content. For total soluble solids, Pusa Bindu × GNRB-1 (13.26%) and Thar Rachita × GNRB-1 (10.87%) were the most promising, and for chlorophyll content, Ajad Brinjal-1 × Swarna Shyamli (13.69%) and Thar Rachita × GNRB-1 (12.22%) recorded the highest standard heterosis. For plant height, Thar Rachita × Pusa Bindu was again the most outstanding hybrid, combining the highest per se performance, the highest sca effect and the highest standard heterosis (26.80%) recorded in the

Table 8: Estimates of standard heterosis (heterosis over check 'Pusa Hybrid-6', %) for growth, yield attributing and quality traits in brinjal.

Cross combination	PH	LA	NFPCL	PC	TSS	CC
TR × PB	26.80**	4.30	177.89**	-10.71**	-0.03	4.40
TR × KU	-15.60*	-2.15	130.00**	-9.29**	-11.23**	2.04
TR × A.B1	-5.46	-6.72	113.33**	-14.34**	-13.25**	3.89
TR × KS-445	-5.61	18.50**	120.15**	-18.23**	-17.39**	6.80
TR × RCBR-22	-32.20**	-2.12	137.28**	-25.95**	-2.90	7.17*
TR × GNRB-1	5.07	3.40	110.00**	-1.40	10.87**	12.22**
TR × S.S	-0.97	-25.18**	176.67**	-33.54**	-11.59**	0.93
PB × KU	7.98	5.21	123.33**	-0.15	-11.08**	1.01
PB × A.B1	14.19*	32.61**	190.00**	-10.55**	4.35	0.92
PB × KS-445	11.90	32.87**	162.25**	-19.67**	-7.46**	-5.32
PB × RCBR-22	-16.57*	-3.43	119.49**	-26.23**	-26.09**	-3.82
PB × GNRB-1	14.29*	0.14	146.11**	2.89	13.26**	5.01
PB × S.S	-6.91	-22.19**	129.00**	-14.27**	-6.67**	-8.97*
KU × A.B1	7.65	26.88**	0.00	-2.96	-6.52**	-1.31
KU × KS-445	0.83	33.79**	0.00	-11.24**	-21.88**	-4.80
KU × RCBR-22	-13.23*	33.76**	0.00	-13.45**	-8.63**	4.59
KU × GNRB-1	-13.56*	8.12	0.00	8.54**	0.29	6.18
KU × S.S	-13.03*	-15.26*	0.00	-7.78**	-16.90**	-3.89
A.B1 × KS-445	-10.42	18.13**	0.00	-10.82**	-15.22**	0.29
A.B1 × RCBR-22	12.55	5.21	0.00	-13.69**	-2.17	-6.38
A.B1 × GNRB-1	14.26*	34.43**	0.00	-4.77	6.52**	-4.26
A.B1 × S.S	9.69	24.47**	0.00	-12.03**	-19.57**	13.69**
KS-445 × RCBR-22	9.54	14.58*	0.00	-24.67**	-20.87**	-5.75
KS-445 × GNRB-1	15.21*	30.67**	0.00	-13.03**	10.87**	-5.21
KS-445 × S.S	-15.95*	-16.37*	0.00	-33.02**	-28.57**	-3.57
RCBR-22 × GNRB-1	-4.00	11.41	0.00	-19.39**	-6.52**	-3.62
RCBR-22 × S.S	-9.47	-4.60	0.00	-36.77**	-13.77**	-8.89*
GNRB-1 × S.S	-3.20	-9.24	0.00	-17.19**	-1.52	-5.28

PH = Plant height at harvest (cm); LA = Leaf area (cm²); NFPCL = Number of fruits per cluster;
PC = Phenol content (mg/100 g); TSS = Total soluble solids (°Brix); CC = Chlorophyll content (SPAD units).
*, ** = significant at 5% and 1% probability levels, respectively.

present study, even though it did not record significant heterobeltiosis.

Taken together, the cross Ajad Brinjal-1 × Swarna Shyamli emerged as the single most consistent performer across the traits studied, combining significant and desirable sca effects and heterosis for plant height, leaf area, phenol content and chlorophyll content, and may be considered a strong candidate for further multi-location evaluation and possible commercial exploitation. Thar Rachita × Pusa Bindu, Pusa Bindu × KS-445, Kashi Uttam × RCBR-22 and Kashi Uttam × GNRB-1 were the other promising specific combinations identified for one or more of the yield-attributing and quality traits under study. The general trend that hybrids showing high sca effects and heterosis frequently, though not invariably, involved at least one parent with favourable gca, particularly for plant height and total soluble solids, while

the best hybrid for several other traits arose from a cross between two comparatively poor general combiners, lends further support to the inference of predominant non-additive gene action for number of fruits per cluster, phenol content and total soluble solids drawn from the combining ability variance ratio (Table 2), and confirms the good scope that exists for exploitation of heterosis breeding for these traits in brinjal, in agreement with the observations of earlier workers (Dixit *et al.*, 1982; Bisht *et al.*, 2009; Reddy and Patel, 2014).

Conclusion

The present investigation revealed the existence of substantial genetic variability among the parents and their half diallel hybrids for plant height, leaf area, number of fruits per cluster, phenol content, total soluble solids and chlorophyll content in brinjal. Combining ability analysis indicated the involvement of both additive and non-additive

gene action in the inheritance of these traits, with plant height, leaf area and chlorophyll content amenable to improvement through selection and number of fruits per cluster, phenol content and total soluble solids offering good scope for exploitation through heterosis breeding. Pusa Bindu, Ajad Brinjal-1, Kashi Uttam and GNRB-1 were identified as the best general combiners and may be usefully employed in recombination breeding programmes aimed at the respective traits. Among the hybrids, Ajad Brinjal-1 × Swarna Shyamli, Thar Rachita × Pusa Bindu, Pusa Bindu × KS-445 and Kashi Uttam × GNRB-1 combined high specific combining ability with significant and desirable heterosis and merit further evaluation across seasons and locations before being considered for commercial hybrid development in brinjal.

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