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Combining Ability Analysis for Biochemical Traits in Spiny Brinjal (*Solanum melongena* L.)

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The present investigation was conducted to estimate the combining ability for important biochemical traits in spiny brinjal (*Solanum melongena* L.) using a full diallel mating design involving five genetically diverse parental lines and their twenty F_1 hybrids. The experimental material comprising twenty hybrids, five parents and one commercial check hybrid ('Sarpan 65') was evaluated in a Randomized Block Design with two replications during January–May 2026 at the Horticulture Farm, Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Karaikal. General combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) were estimated following Griffing's diallel analysis (Model I). Four biochemical traits, namely total phenol content, ascorbic acid content, protein content and proline content, were evaluated. Parent P_2 exhibited superior general combining ability for total phenol and protein content, whereas P_3 was identified as the best general combiner for ascorbic acid content and P_4 for proline content. The hybrids $P_2 \times P_4$, $P_3 \times P_4$ and $P_2 \times P_3$ recorded significant positive specific combining ability effects for most biochemical traits, indicating the predominance of non-additive gene action. The identified superior combiners and cross combinations may be effectively utilized for developing nutritionally superior hybrids and breeding populations in spiny brinjal.

Introduction

Brinjal (*Solanum melongena* L.), popularly known as eggplant or aubergine, is one of the most important solanaceous vegetable crops cultivated throughout tropical and subtropical regions of the world. India is regarded as one of the primary centres of diversity for brinjal and possesses enormous variability for fruit shape, colour, size, quality attributes and resistance to biotic and abiotic stresses. Among the different forms of cultivated brinjal, spiny brinjal represents a valuable indigenous genetic resource characterized by its adaptability, unique fruit quality and tolerance to several production constraints. The crop occupies an important position in vegetable production owing to its year-round availability, high productivity and wide consumer acceptance.

Besides its economic importance, brinjal is recognized for its nutritional and functional properties. The fruits are rich in vitamins, minerals, dietary fibre and several bioactive compounds such as phenolics, flavonoids, anthocyanins and antioxidants that contribute to human health. Total phenolic compounds are known to possess strong antioxidant activity and help reduce oxidative stress. Ascorbic acid serves as an important natural antioxidant and plays a significant role in improving nutritional quality. Protein contributes to the nutritional value of the fruits, while proline functions as an osmoprotectant and is associated with stress tolerance in plants. Therefore, improvement of biochemical quality traits has become an important objective in modern brinjal breeding programmes.

Selection of suitable parents is one of the most crucial steps in any hybridization programme. The success of hybrid breeding largely depends on the combining ability of parental lines, which determines their potential to produce superior progenies. Diallel mating design is one of the most efficient biometrical approaches for evaluating combining ability among parents and for understanding the nature of gene action controlling economically important traits. General combining ability (GCA) is primarily associated with additive gene effects, whereas specific combining ability (SCA) reflects dominance and epistatic interactions arising from non-additive gene action. Estimation of both GCA and SCA provides valuable information for identifying superior parents and promising hybrid combinations for crop improvement.

The exploitation of heterosis in brinjal has resulted in the development of several commercial hybrids with higher productivity and improved fruit quality. However, limited information is available regarding the inheritance of biochemical traits in spiny brinjal.

Identification of good general combiners and specific cross combinations for these quality attributes would facilitate the development of nutritionally superior hybrids and breeding populations.

Therefore, the present investigation was undertaken using a full diallel mating design involving five diverse spiny brinjal parents to estimate general combining ability, specific combining ability and reciprocal combining ability for important biochemical traits including total phenol content, ascorbic acid content, protein content and proline content. The study aimed to identify superior parental lines and hybrid combinations that could be effectively utilized in future breeding programmes for quality improvement in spiny brinjal.

Materials and Methods

Plant materials and experimental site

The present investigation was carried out at the Horticulture Farm, Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Karaikal, U.T. of Puducherry, India, during 2024–2026. The experimental farm is situated between 10°49′–11°01′ N latitude and 79°52′ E longitude at an altitude of 4 m above mean sea level. The experimental field consisted of sandy loam soil with moderate fertility and the crop was irrigated using water from the rainwater harvesting pond located in the Eastern Farm of the institute.

Experimental materials

Five genetically diverse spiny brinjal genotypes were selected as parents based on their performance in preliminary evaluation. The parents were crossed in a full diallel mating design to generate 20 F_1 hybrids, including reciprocal crosses. Controlled hybridization was carried out during January–July 2025 by following standard emasculation and hand-pollination techniques. Emasculation was performed during the evening (3.00–5.00 PM), and pollination was carried out the following morning (6.00–8.00 AM).

Selfed and crossed flowers were properly bagged and tagged to ensure genetic purity. Mature fruits were harvested, seeds extracted, shade dried and stored for subsequent evaluation.

Evaluation of parents and hybrids

The twenty F_1 hybrids, five parents and one commercial hybrid (Sarpan 65) were evaluated during January–May 2026 in a Randomized Block Design (RBD) with two replications. Each treatment consisted of 15 plants maintained at a spacing of 75 × 60 cm. Five competitive plants from each genotype in every replication were randomly selected for recording observations. All recommended agronomic and plant protection practices were uniformly followed throughout the crop growth period.

Estimation of biochemical traits

Biochemical analyses were carried out using mature fruits collected from representative plants of each genotype.

Total phenol content was estimated following the Folin–Ciocalteu method described by Bray and Thorpe (1954). The absorbance of the blue-coloured complex was measured at 650 nm, and the phenol content was expressed as mg 100 g^{-1} fresh weight.

Ascorbic acid content was determined by the volumetric method of Sadasivam and Manickam (1996) using 2,6-dichlorophenol indophenol dye. The results were expressed as mg 100 g^{-1} fresh weight.

Protein content was estimated according to the method of Lowry *et al.,* (1951) using bovine serum albumin as the standard. The absorbance was recorded at 660 nm, and protein content was expressed as percentage.

Proline content was estimated using the acid ninhydrin method described by Sadasivam and Manickam (1996). The absorbance of the chromophore was measured at 520 nm, and proline concentration was expressed as µmol g^{-1} fresh weight.

Statistical analysis

Combining ability analysis was performed using Griffing's diallel analysis (Model I, Method I) to estimate general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects. Analysis of variance was carried out to partition the variation into GCA, SCA and reciprocal components. The significance of combining ability effects was tested using the respective standard errors. The formulas for estimating GCA, SCA and RCA effects were adopted according to Griffing's diallel methodology.

Results and Discussion

Combining ability for biochemical traits

Total phenol content

The estimates of GCA, SCA and RCA effects for total phenol content are presented in Table 1. The GCA effects indicated that P_2 (0.04) was the best general combiner followed by P_4 (0.03), suggesting the predominance of favourable additive gene effects for phenol accumulation in these parents. In contrast, P_5 (-0.07*) exhibited a significant negative GCA effect, indicating poor combining ability for this trait.

Among the hybrid combinations, $P_2 \times P_4$ (0.14**) recorded the highest positive and significant SCA effect, followed by $P_2 \times P_3$ (0.12**), $P_1 \times P_5$ (0.11**), $P_3 \times P_4$ (0.11**) and $P_3 \times P_5$ (0.10**). The superior performance of these hybrids suggested the importance of non-additive gene action governing total phenol content. Significant reciprocal effects observed in $P_2 \times P_3$, $P_3 \times P_4$ and $P_4 \times P_5$ indicated the influence of maternal effects on the inheritance of this trait.

The simultaneous occurrence of favourable GCA and SCA effects suggests that both additive and dominance gene actions contributed to the expression of total phenol content. Therefore, parents P_2 and P_4 could be effectively utilized in recombination breeding programmes, whereas hybrids such as $P_2 \times P_4$ may be exploited for heterosis breeding aimed at improving antioxidant potential in spiny brinjal.

Combining ability for ascorbic acid content

The estimates of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects for ascorbic acid content are presented in Table 2. Considerable variation was observed among the parents and hybrids, indicating ample scope for the genetic improvement of this nutritional trait.

Among the parental lines, P_3 (0.70**) exhibited the highest positive and highly significant GCA effect, followed by P_2 (0.29) and P_1 (0.26), indicating that these parents possessed favourable additive genes governing ascorbic acid accumulation. On the contrary, P_4 (-0.95**) and P_5 (-0.30*) recorded significant negative GCA effects and were considered poor general combiners.

The SCA effects revealed that $P_3 \times P_4$ (1.59**) was the best specific combiner for ascorbic acid content, followed by $P_2 \times P_4$ (1.52**), $P_4 \times P_5$ (1.41**), $P_2 \times P_3$ (1.10**), $P_1 \times P_4$ (1.08**) and $P_3 \times P_5$ (0.77**). These highly significant positive SCA effects indicated that non-additive gene action played a predominant role in the inheritance of ascorbic acid content. Similar observations have been reported in brinjal by several researchers who emphasized the importance of dominance and epistatic interactions for quality traits.

Significant reciprocal effects were observed in $P_2 \times P_3$, $P_2 \times P_4$, $P_3 \times P_4$ and $P_4 \times P_5$, suggesting that maternal effects also contributed to the expression of ascorbic acid content. Therefore, the direction of crossing should be considered while developing hybrids for enhanced vitamin C content.

The superior GCA of P_3 and the outstanding SCA of the cross $P_3 \times P_4$ suggest that these parental combinations can be effectively utilized in hybrid breeding programmes aimed at improving fruit nutritional quality.

Combining ability for protein content

The combining ability estimates for protein content are presented in Table 3. The GCA effects indicated that P_2 (0.01) and P_4 (0.01) were the best general combiners for protein content, whereas P_3 (-0.01) and P_5 (-0.01) recorded negative GCA effects. Among the hybrids, $P_2 \times P_3$ (0.06**) exhibited the highest positive SCA effect followed by $P_2 \times P_4$ (0.04**), $P_3 \times P_4$ (0.04**), $P_4 \times P_5$ (0.03**), $P_1 \times P_3$ (0.03**), $P_1 \times P_5$ (0.02*) and $P_2 \times P_5$ (0.02*). These crosses may therefore be considered promising hybrid combinations for improving protein content in spiny brinjal.

The predominance of significant SCA effects over GCA effects indicated that non-additive gene action was relatively more important in controlling protein content. Similar findings have been reported in earlier diallel studies on brinjal where dominance effects were found to contribute substantially to quality traits.

Reciprocal combining ability effects were significant in $P_1 \times P_4$, $P_2 \times P_3$, $P_2 \times P_4$, $P_3 \times P_4$ and $P_2 \times P_5$, indicating that cytoplasmic and maternal influences also affected protein accumulation. These results suggest that appropriate selection of female parents would improve breeding efficiency for this trait.

Overall, the cross $P_2 \times P_3$ emerged as the most promising hybrid for protein content owing to its highly significant positive SCA effect.

Combining ability for proline content

The estimates of GCA, SCA and RCA effects for proline content are presented in Table 4. Among the parents, P_4 (0.12) exhibited the highest positive GCA effect followed by P_2 (0.06), indicating that these parents possessed favourable additive genes responsible for proline accumulation. Negative GCA effects were observed in P_3 (-0.06) and P_5 (-0.08).

The hybrid $P_2 \times P_4$ (0.32**) recorded the highest significant positive SCA effect followed by $P_2 \times P_3$ (0.30**), $P_3 \times P_5$ (0.29**), $P_1 \times P_4$ (0.25**), $P_2 \times P_5$ (0.18*) and $P_4 \times P_5$ (0.15*). These hybrids demonstrated superior specific combining ability for proline content and may therefore be exploited in heterosis breeding programmes.

Significant reciprocal effects were observed in $P_2 \times P_3$, $P_2 \times P_4$, $P_1 \times P_3$ and $P_3 \times P_5$, indicating the involvement of maternal inheritance in the expression of proline content.

Similar reciprocal effects have been reported in brinjal for biochemical characters, suggesting that cytoplasmic factors contribute to stress-related biochemical responses.

The higher magnitude of SCA effects compared with GCA effects suggested that dominance and epistatic interactions predominantly governed proline accumulation in spiny brinjal.

The present investigation clearly demonstrated the existence of considerable genetic variability among the parental lines for all four biochemical traits. Positive and significant GCA effects observed in P_2, P_3 and P_4 indicated that these parents possess favourable additive genes and can serve as valuable donors in future breeding programmes. Parent P_2 was identified as a good general combiner for total phenol and protein content, whereas P_3 was the best general combiner for ascorbic acid content and P_4 for proline content.

Several hybrids exhibited highly significant positive SCA effects, particularly $P_2 \times P_4$, $P_3 \times P_4$, $P_2 \times P_3$ and $P_3 \times P_5$, indicating the predominance of non-additive gene action. Such crosses are suitable candidates for commercial hybrid development owing to their superior performance for biochemical quality traits.

Significant reciprocal combining ability effects observed for several crosses further indicated that maternal and cytoplasmic effects contributed to the inheritance of biochemical traits. Therefore, careful selection of female parents should be considered while designing hybridization programmes in spiny brinjal.

Table.1 Estimates of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects for total phenol content in spiny brinjal (*Solanum melongena* L.)

Parents	P_1	P_2	P_3	P_4	P_5
P_1	**-0.00**	-0.01	0.03	0.01	0.11**
P_2	0.01	**0.04**	0.12**	0.14**	0.09**
P_3	-0.03	0.09**	**-0.00**	0.11**	0.10**
P_4	-0.06	0.02	0.07*	**0.03**	-0.00
P_5	-0.04	-0.04	-0.04	0.05	**-0.07***

Parameter	SE
GCA (gi)	0.02
SCA (Sij)	0.04
RCA (rij)	0.05

Diagonal values = GCA; Above diagonal = SCA; Below diagonal = RCA.
*Significant at P = 0.05; ** Significant at P = 0.01.*

Table.2 Estimates of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects for ascorbic acid content in spiny brinjal (*Solanum melongena* L.)

Parents	P_1	P_2	P_3	P_4	P_5
P_1	**0.26**	0.30	-0.28	1.08**	0.40*
P_2	-0.78*	**0.29**	1.10**	1.52**	0.19
P_3	0.27	0.81**	**0.70**	1.59**	0.77**
P_4	0.41	1.04**	0.56**	**-0.95**	1.41**
P_5	0.32	-0.10	-0.11	0.47*	**-0.30***

Parameter	SE
GCA (gi)	0.13
SCA (Sij)	0.28
RCA (rij)	0.34

Diagonal values = GCA; Above diagonal = SCA; Below diagonal = RCA.
*Significant at P = 0.05; ** Significant at P = 0.01.*

Table.3 Estimates of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects for protein content in spiny brinjal (*Solanum melongena* L.)

Parents	P_1	P_2	P_3	P_4	P_5
P_1	**-0.00**	-0.02	0.03**	0.00	0.02*
P_2	0.01	**0.01**	0.06**	0.04**	0.02*
P_3	-0.01	0.02*	**-0.01**	0.04**	0.00
P_4	0.03**	0.02*	0.02*	**0.01**	0.03**
P_5	0.00	0.02*	0.00	0.00	**-0.01**

Parameter	SE
GCA (gi)	0.01
SCA (Sij)	0.01
RCA (rij)	0.01

Diagonal values = GCA; Above diagonal = SCA; Below diagonal = RCA.
*Significant at P = 0.05; ** Significant at P = 0.01.*

Table.4 Estimates of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) effects for proline content in spiny brinjal (*Solanum melongena* L.)

Parents	P_1	P_2	P_3	P_4	P_5
P_1	**-0.04**	-0.21*	0.09	0.25**	0.05
P_2	0.05	**0.06**	0.30**	0.32**	0.18*
P_3	-0.16*	0.37**	**-0.06**	0.13	0.29**
P_4	-0.02	0.14*	0.05	**0.12**	0.15*
P_5	-0.03	0.06	-0.14*	-0.17*	**-0.08**

Parameter	SE
GCA (gi)	0.04
SCA (Sij)	0.09
RCA (rij)	0.10

Diagonal values = GCA; Above diagonal = SCA; Below diagonal = RCA.
*Significant at P = 0.05; ** Significant at P = 0.01.*

The simultaneous occurrence of additive and non-additive gene actions suggests that both recombination breeding and heterosis breeding can be effectively employed to improve the nutritional quality of spiny brinjal. Selection from segregating generations of superior general combiners together with the exploitation of highly specific combining hybrids would accelerate the development of nutritionally superior cultivars.

In conclusion, the diallel analysis revealed significant variability among the parental lines and hybrids for biochemical traits in spiny brinjal. Parent P_2 was identified as an efficient general combiner for total phenol and protein content, while P_3 and P_4 were superior general combiners for ascorbic acid and proline content, respectively. The hybrids $P_2 \times P_4$, $P_3 \times P_4$, $P_2 \times P_3$ and $P_3 \times P_5$ exhibited high positive specific combining ability effects and were identified as promising combinations for quality improvement.

The predominance of non-additive gene action for most biochemical traits suggested that heterosis breeding would be an effective approach for developing nutritionally superior spiny brinjal hybrids. The superior general combiners may also be utilized in recombination breeding programmes to develop improved breeding lines with enhanced biochemical quality.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Author Contributions

Priyanga S designed the study, conducted the experiment, collected and analysed the data, and prepared the original manuscript. V. Kanthaswamy supervised the research work, guided the experimental design, interpreted the results, and critically reviewed the manuscript. M. S. Marichamy assisted in planning the experiment, data interpretation, and manuscript revision. V. Krishnan contributed to data validation, statistical interpretation, and critical review of the manuscript. N. Bavya assisted in data collection, compilation of literature, and manuscript editing. B. Bavithra assisted in field observations, data recording, and manuscript preparation. All authors read and approved the final manuscript.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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