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Genetics and heterosis of quality and yield of brinjal (*Solanum melongena* L.)

Lokesh Yadav[1], B Singh[2*], Aastik Jha[1], C N Ram[1] & D K Upadhyay[1*]

[1]Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya 224 229, India

[2]Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya 224 229, India

*Email: vcnduat2018@gmail.com, dhananjay.gpb2011@gmail.com

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Abstract

A study on gene action, combining ability and heterosis for quality and yield attributes in brinjal involving 45 cross combinations from ten diverse inbred lines using a half-diallel method , was conducted. The findings showed that non-additive gene action was more important for yield traits than additive gene action for quality traits like total phenol content, total soluble solids, reducing sugar, non-reducing sugar, total sugar, ascorbic acid and dry matter. Inbreds like NDB-2 and NDB.Sel-16-1 demonstrated a high general combining ability (GCA) for both non-reducing and total sugars. Punjab Sadabahar and NDB-3 demonstrated superiority in total phenol content, whereas NDB-2 and NDB.Sel-19-1 stood out in terms of total soluble solids. NDB-2 also had high GCA for total sugars and dry matter, making it a key inbred for future breeding. The cross NDB-3 × Arka Nidhi exhibited the highest specific combining ability (SCA) for reducing sugars and dry matter, while Pant Samrat × Pusa Purple Long had the highest SCA for total phenol content. Combinations like NDB.Sel-19-1 × NDB-3 for total soluble solids and Punjab Sadabahar × Pusa Kranti for non-reducing sugar were also promising. Over better parent heterosis varied between 17.56% to 72.26% for yield. The range of heterosis over mid-parent varied between 11.93 to 72.74% for yield. The highest heterosis over better parent was recorded in Punjab Sadabahar × Pant Rituraj (72.26 %) followed by Pusa Purple Long × Pant Rituraj (63.36 %) and NDB-2 × Pant Rituraj (55.57 %) for yield. Whereas over mid-parent cross combination Pusa Purple Long × Pant Rituraj (72.74%), Punjab Sadabahar × Pant Rituraj (72.63 %) and Arka Nidhi × Pant Rituraj (65.32%) exhibited maximum heterosis. Overall, the study concluded that improving brinjal for quality traits could be achieved through recurrent selection, while yield enhancement may be pursued through hybridization, paving the way for the development of high-quality, high-yielding brinjal varieties.

Keywords

ascorbic acid; brinjal; combining ability; genetics; heterosis; *Solanum melongena*

Introduction

Brinjal (*Solanum melongena* L.) is a major and widely cultivated solanaceous vegetable crop, characterized by its often cross-pollination and annual herbaceous nature. It demonstrates significant adaptability to various agro-climatic conditions, allowing for year-round cultivation (1, 2). Out of the 38 Asian species, 22 are available in India (3). Primary gene pool species such as *S. melongena*, *S. incanum*, *S. xanthocarpum*, *S. indicum* and *S. maccani* are crossable and can facilitate the introduction of desirable alleles (4,5). It is a significant crop in the tropical parts of the world and is cultivated abundantly in India, Bangladesh, Pakistan, China, the Philippines, Egypt, France, Italy and the United States. Glycoalkaloids contain antibacterial, insecticidal and fungicidal activities, which explain their effectiveness against a variety of insects, pests and herbivores. Small amounts of glycoalkaloids are known to increase flavour, but at concentrations exceeding 200 mg/kg, they contribute a bitter taste. The current production is insufficient to meet the rapidly growing population's needs. Brinjal demands careful consideration for improvement because customer tastes vary across countries based on fruit shape, size and colour. In this sense, buyers favour local cultivars with desirable features but poor yield. This necessitates improvements in yield and other economic characteristics in these cultivars. Brinjal fruits come in a variety of sizes and colors, from round or egg-shaped to long club-shaped and from white, yellow and green to practically black, with varying degrees of grandiloquent saturation. The long-standing varieties found in China and tropical India are the source of many economically significant variations. Its unripe fruit is generally consumed cooked in various ways its delicate fruits are frequently consumed as vegetables and the dried shoots are utilized as a fuel in rural areas. Due to its year-round availability, ease of production, moderate to high yield and use in a range of recipes including bhaji, stuffed brinjal, bhartha, pickles, *etc.*, the brinjal has grown in popularity in India.

Its fruits are commonly utilized in a wide range of culinary preparations and are a rich source of preventative components (6). It is cooked, grilled, fried and spiced like a vegetable. It is also used to make fish curries and sambar.

Eggplants have ayurvedic therapeutic effects (7, 8). The fruit is used to treat diabetes, bronchitis and asthma, dysuria, dysentery, high blood pressure, osteoporosis, arthritis, Alzheimer's, some forms of cancer (skin, colon, stomach), heart disease and stroke (9,7). Furthermore, the ripe fruits are utilized to treat stomach problems, abscesses and broken nipples (8, 10). The fruit stem is also used to treat fistulas and piles (8) and the fruit juice (often combined with crushed leaves) is used to treat syphilitic sores of the hands (10).

In order to treat skin conditions, rheumatism, inflammation, intestinal haemorrhages, foot pain, cough, otitis, anorexia, toothache, burns, general stimulants, piles, throat and stomach issues, the leaves and roots are juiced and cooked to make a tonic (7, 10, 11).

Nutritionally, brinjal is low in calories and fats, predominantly composed of water, with moderate amounts of protein, fiber and carbohydrates. It contains a high amount of carbohydrates (6.4%), protein (1.3%), fat (0.3%), calcium (0.02%), phosphorus (0.02%), iron (0.0013%) and other mineral matter. It also contains β-carotene (34 mg), riboflavin (0.05 mg), thiamine (0.05 mg), niacine (0.5 mg) and ascorbic acid (0.9 mg) per 100 g of fruit (12).

Understanding general combining ability (GCA) and specific combining ability (SCA) is essential for selecting hybrid parents and determining the gene action involved, which allows us to choose effective breeding methodologies. However, heterosis provides insights into the optimal parent combinations for hybrid development and the gene action underlying desirable traits. This study aims to identify promising parental combinations to develop superior brinjal hybrids. Keeping in view the above facts, the present investigation was undertaken to evaluate the information on the combining ability and heterosis of brinjal lines for fruit yield and its component traits in addition to the identification of well-performing hybrids.

Materials and Methods

Ten diverse brinjal inbred *viz*, Punjab Sadabahar, NDB. Sel-19-1, Pant Samrat, NDB. Sel-16-1, NDB-2, NDB-3, Pusa Kranti, Pusa Purple Long, Arka Nidhi and Pant Rituraj were selected and crossed with all possible combinations (45 F_1) excluding reciprocals. The F_1s and parents were evaluated under complete randomized block design (RBD) in three replications at the Main Experimental Station, Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh during 2023 and 2024. Seedlings were transplanted at a spacing of 60 cm × 60 cm (row to row and plant to plant) with 3 replications, plot size 1.2 m × 3 m and all the standard packages and practices were followed (13).

Observations were recorded on ten competitive plants in each parent and F_1s for each treatment in each replication selected at random for total phenol content (%), total soluble solid (°B), non-reducing sugar (%), reducing sugar (%), total sugar, ascorbic acid (mg/100g), dry matter content (%) and yield per hectare (qt). The Combining ability variance and effect were worked out according to (14) and heterosis was worked out over better and mid-parents.

Estimation of heterosis

The magnitude of heterosis was studied using information on various quantitative and fruit quality traits. Heterosis expressed as per cent increase or decrease in the mean values of F1's (hybrid) over better-parent (heterobeltiosis) and standard variety (standard heterosis) was calculated according to the method suggested by Hayes *et al.* (15). The formulas used for the estimation of heterosis are as follows:

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SV}}{\overline{SV}} \times 100$$

Where,

F_1 = Mean value of F_1

BP = Mean value of better parent

SV = Mean value of standard variety

The significance of heterosis was tested by 't' teat as given below:

‘t’ (Heterobeltiosis) = $\frac{\bar{F}_1 - \overline{SV}}{SE}$

‘t’ (Standard heterosis) = $\frac{\bar{F}_1 - \overline{BP}}{SE}$

SE of heterosis over better-parent and standard variety = $\sqrt{\frac{Me}{r}}$

Where,

Me = Error mean of square

r = Number of replications

SE = The standard error of the treatments mean and (t) is the table value of (t) at 5% or 1% level of significance at error of degree of freedom.

The calculated ‘t’ value was compared with table value ‘t’ at error d.f. at 5% and 1% level of probability for testing the significance of heterosis.

Combining ability variances and their effects

The combining ability analysis for different characters was carried out following the method 2 model 1 of Griffing (14), where parents and F_1s were included but not the reciprocals. Thus, the experimental material for this method comprises of n (n-1)/2 genotypes.

The mathematical model for the combining ability analysis is assumed to be:

$$Y_{ij} = \mu + g_i + g_i + S_{ij} + \frac{1}{bc} \sum\sum e_{ijkl}$$

Where,

i, j = 1, 2, …, p (p = number of parents involved in diallel)

K = 1, 2, ……, r (r = number of replications)

L = 1, 2, ……, c (c = number of observations taken in each plot)

μ = the population mean

g_i, g_j = gca effect of i^{th} and j^{th} parents, respectively

Sij = the interaction, *i.e.* the specific combining ability (sca) for the cross between i^{th} and j^{th} parents such that Sij = Sji.

eijkl = environmental effect associated with ijklth observation. The restriction imposed on this mathematical model are:

i. $\sum_i gi = 0$

ii. $\sum S_{ij} = 0$

The orthogonal partitioning of the variety sum of squares in the ANOVA is as follows:

Analysis of variance table for method 2, model 1, with expectations of mean squares.

Source	d.f.	Sum of square	Mean square	Expectations of mean squares
Gca	p-1	Sg	Mg	σ_e^2 +(p+2 $\left(\frac{1}{p-1}\right) \sum_{X=1}^{p} g_i^2$
Sca	p(p-1)/2	Ss	Ms	σ_e^2 $+\left(\frac{2}{p(p-1)}\right) \sum_{i=1}^{p} \sum_{j=1}^{p} s_{ij}^2$
Error	(r-1) (t-1)	Se	Me	σ_e^2

Where,

P = Number of parents

$$S_g = \frac{1}{P+2}\left[\sum_{i=1}(Y_i + Y_{ii})^2 - \frac{4}{P} Y^2\right]$$

$$S_s = \sum_i \leq \sum_j Y_{ij}^2 - \frac{1}{P+2} \sum_{i=2}(Y_i + Y_{ii})^2 + \frac{2}{(P+1)(P+2)} Y^2$$

Y_i = Total of the array involving of i^{th} parent

Y_{ii} = Mean value of the i^{th} parent of the array

Y_{ij} = Mean value of i × j^{th} cross

Y = total of all the elements in the diallel table without reciprocals

$$\left(\frac{P(P-1)}{2} \textit{ progenies and P parental lines}\right)$$

M_e = Error mean square

M_g and M_s were obtained by dividing each sum of squares by the corresponding degree of freedom, while M_e was obtained by dividing the error mean square by the number of replications. The following ‘F’ ratios were used for testing the significance of GCA and SCA effects.

i) To test the significance of differences among GCA effects of a character,

$$F = \frac{Mg}{Me}$$

The calculated F- value is tested against table F- value at (P-1) vs. error degree of freedom.

ii) To test the significance of differences among SCA effects of characters.

$$F = \frac{Mg}{Me}$$

The calculated F-value is tested against table F-value at [P (P-1)/2] vs error degree of freedom.

Total Phenol Content (TPC)

The Folin-Ciocalteu method is commonly used (16). Exactly 0.5 mg of sample weighed and ground with a pestle and mortar in a 10-time volume of 80% ethanol. Centrifuged and homogenated at 10000 rpm for 20 min. Saved the supernatant. Re-extracted the residue five times with the volume of 80% ethanol, centrifuged and pooled the supernatant and evaporated the supernatant to dryness. Dissolve the residue in a known volume of distilled water (5 mL). Pipette out different aliquots (0.2 to 2.0 mL) into test tubes and make up the volume in each tube to 3 mL with water. Added 0.5 mL of Folin-Ciocalteu reagent. After 3 min, added 2 mL of 20% Na2CO3 solution to each tube and mix thoroughly. Placed the tubes in boiled water for exactly 1 min, cooled and measured the absorbance at 650 nm against a reagent blank. Prepared a standard curve using different concentrations of ethanol. Form the standard curve find out the concentration of phenol in the test sample and express as mg phenol/100 gm materials. If any white precipitate is observed on boiling, the colour may be developed at room temperature for 60 min. Expressed the results in terms of catechol or any other phenol equivalent used as standard.

Total soluble solid (T.S.S.) (°Brix)

The total soluble solid of the juice of fresh fruit of each strain/line/F_1's was determined with the help of hand refractometer (Erma, Japan) of 0-32 % range. The values were collected at 20°C and expressed as per cent T.S.S. of fresh fruit juice.

Non-reducing sugar (%)

Non-reducing sugar was calculated by deducting the quantity of reducing sugars from total inverted sugars and multiplying by a factor of 0.95. The results were expressed as per cent (%) non-reducing sugar.

Reducing sugar (%)

Reducing sugars were estimated by Fehling's 'A' and 'B' solution method given by Ranganna (1991) (17). 10 g fresh fruit was macerated in a small amount of distilled water and filtered through muslin cloth and maintain volume up to 100 mL. An aliquot of 5 mL diluted fruit juice was taken from 100 mL as above for titration and mixed with 10 mL of Fehling 'A' and 'B' solution each. This mixture was titrated against 1.0% glucose and a blank with 10 mL of Fehling 'A' and 'B' was also run. The results were expressed as percent (%) reducing sugars. For total inverted sugars, out of 100 mL sample, 5 mL aliquot was taken and mixed with three drops of HCl and kept overnight. Next day 2–3 drops of phenolphthalein indicator were added and neutralized with 30% sodium hydroxide (NaOH) solution containing 10 mL Fehling 'A' and 'B'. This mixture was titrated against 1.0% glucose in boiling solution using a methylene blue indicator. The appearance of red brick colour was marked as the endpoint. The results were expressed as percent (%) total invert sugars.

Total sugars

Total sugars were calculated by taking the sum of reducing sugars and non-reducing sugars. The result was expressed as percent (%) of total sugars. To determine the sugar content procedure suggested by (18) was used.

Ascorbic acid (Vitamin C)

The ascorbic acid content of the sample was determined following standard biochemical methods by AOAC, 1990 (19). 100 mg of ascorbic acid was dissolved in 100 mL of 3% metaphosphoric acid in a standard flask. 10 mL of this solution was taken and was diluted to 100 mL with 3% metaphosphoric acid (working standard solution). 42 mg sodium bicarbonate was taken into a small volume of distilled water and 52 mg of 2, 6 dichlorophenol indophenols was dissolved in it. The volume was then made to 200 mL with distilled water. 5 mL of the working standard solution was pipetted out into a conical flask and 10 mL metaphosphoric acid was added to it and titrated against the dye solution (V1 mL). End point was appearance of pink colour which persisted for a few minutes, The amount of dye consumed was equivalent to the amount of ascorbic acid. 5g of the sample was crushed and extracted in 3% metaphosphoric acid. The volume was made to 100 mL and centrifuged for 20 min. 5mL of this supernatant was pipetted out and added into the 10 mL of 3% metaphosphoric acid. It was titrated against the dye (V2 mL) (20).

$$\text{Amount of ascorbic acid mg/100g sample} = \frac{0.5 \text{ X } V2 \text{ X } 100}{\text{V1 X 5 X Weight of sample}}$$

Dry matter content (%)

The dry matter content in fruit was determined on a fresh weight basis. A quantity of 100 g of fresh fruit was taken, cut into small pieces and allowed sun drying and then dried in an oven at 40±2°C for 8-10 h per day till the complete drying to have constant weight and dry matter percentage was calculated as:

$$\text{Dry matter (\%)} = \frac{\text{Dry matter of sample (g)}}{\text{Fresh weight of sample (g)}} \text{ X } 100$$

Results and Discussion

The analysis of variance showed significant differences in treatments for all the characters except non-reducing, ascorbic acid and dry matter content for parent *vs* F_{1s} (Table 1). The t^2 value is non-significant for all the characters indicating the validity of hypothesis pertaining to diallel cross analysis. The estimate of H_1 and H_2 were significant and higher than that of D for all the characters. The estimate of F, h_2 and Ĕ components was positive and significant indicating an excess of the dominant gene. The $(H_1/D)^{1/2}$ showed overdominance for all characters (21-25). The ratio $H_2/4H_1$ indicated asymmetrical distribution of positive and negative genes among the parents (26). The proportion of KD/KR was more than unity indicating excess of dominant gene except TPC. The ratio of h_2/H_2 indicates one gene group controlling characters and exhibiting dominance. The correlation was positive and non-significant for all the characters (Table 2).

Table 1. Analysis of variance for quality and yield in brinjal

Source of variation	df	Total phenol content	Total soluble solid	Non reducing sugar	Reducing sugar	Total sugar	Ascorbic acid	Dry matter content	Yield per hectare
Replication	2	0.002	0.01	0.001	0.002	0.004	0.162	0.087	237.099
Treatment	54	0.072 **	0.367 **	0.032 **	0.117 **	0.147 **	10.258 **	0.615 **	5612.98**
Parent	9	0.069 **	0.474 **	0.042 **	0.150 **	0.169 **	10.517 **	0.616 **	1139.31**
F_1S	44	0.064 **	0.350 **	0.030 **	0.111 **	0.143 **	10.431 **	0.627 **	5456.85**
PvF1	1	0.448 **	0.181 *	0.001	0.067 **	0.124 **	0.288	0.07	52746.14**
Error	108	0.002	0.027	0.002	0.002	0.003	0.15	0.122	400.218

** Significant 1 % level of probability.

Table 2. Genetic parameters and their related statistics for quality and yield

Genetic parameters related statistics	Total phenol content	Total soluble solid	Non-reducing sugar	Reducing sugar	Total sugar	Ascorbic acid	Dry matter content	Yield per hectare
D	0.02*±0.004	0.15*±0.05	0.01*±0.01	0.05*±0.01	0.05*±0.02	3.46*±1.34	0.16*±0.08	247.35±267.11
F	0.02±0.01	0.24*±0.12	0.03*±0.01	0.08*±0.02	0.11*±0.05	7.04*±3.08	0.03±0.18	642.33±616.30
Ĥ	0.07*±0.009	0.53*±0.11	0.06*±0.01	0.19*±0.03	0.26*±0.04	16.94*±2.84	0.90*±0.16	6346.73*±568.57
H_2	0.06*±0.008	0.38*±0.09	0.04*±0.01	0.15*±0.02	0.19*±0.04	11.83*±2.41	0.67*±0.14	4095.72*±483.22
ĥ1	0.06*±0.005	0.02±0.06	0.00±0.00	0.009±0.01	0.02±0.03	0.02±1.61	-0.005±0.09	6914.82*±323.45
Ĕ	0.001±0.001	0.009±0.015	0.00±0.00	0.001±0.004	0.001±0.01	0.05±0.40	0.04±0.02	132.42±180.54
$(h/D)^{0.5}$	1.82	1.88	1.99	1.99	2.14	2.21	2.34	5.06
$H_2/4H_2$	0.22	0.18	0.18	0.19	0.19	0.17	0.18	0.16
KD/KR	0.46	2.48	2.84	2.59	2.66	2.70	2.51	1.69
H^2/H_2	0.91	0.05	0.00	0.06	0.08	0.00	-0.008	1.69
r	0.79	-0.019	0.28	-0.09	-0.49	-0.20	0.15	0.69
t^2	1.38	0.06	0.27	3.93	-0.04	2.64	0.18	11.01

** Significant at 1% level of probability.

Highly significant variances were observed for both general and specific combining ability for all the characters indicating that parents and crosses differ significantly with regard to their general and specific combining ability, respectively. The *gca* variance was higher than the *sca* variance except for non-reducing, reducing sugar, total sugar, ascorbic acid and dry matter content. The gca/sca variance ratio is less than unity for most of the characters revealing predominance of non-additive components of variance. The importance of both additive as well as non-additive components for number of fruits per plant, branches per plant, plant height and yield (kg/plot and q/ha) in brinjal (27). The general combining ability (gca) effects revealed that the parents used were found good general combiner for most of the characters. Variance due to general combining ability was less than the variance due to SCA and the ratio of GCA to SCA variance was less than unity. This indicated the limited scope of heterosis breeding for these characters and population improvement through recurrent selection should be adopted for exploiting the genetic variations (28,29) (Table 3).

The gca variance is higher than sca variance for yield character so it indicates the predominance of non-additive gene effect. The information regarding *gca* effect of the parent is of prime importance, as it helps in successful prediction of genetic potentiality of crosses. Estimates of *gca* effect showed that it is difficult to pick up a good general combiner for all the characters. However, overall evaluation indicates that NDB-3 and Arka Nidhi were best general combiner for yield and quality traits on the basis of *per se* performance and significant *gca* effects. Similarly, on the basis of *per se* performance and significant *gca* effects, NDB-3 was a good general combiner for TPC and yield. NDB-2 was best general combiner for total soluble solid, non-reducing sugar, total sugar and dry matter content. while Punjab Sadabahar was best general combiner for reducing sugar and Pusa Kranti for ascorbic acids, respectively (Table 4).

Table 3. Analysis of variance for combining ability for quality and yield

Source of variance	d. f.	Total phenol content	Total soluble solid	Non-reducing sugar	Reducing sugar	Total sugar	Ascorbic acid	Dry matter content	Yield per hectare
Gca	9	0.050**	0.174**	0.007**	0.019**	0.020**	3.448**	0.177**	3914.11**
Sca	45	0.019**	0.112**	0.011**	0.043**	0.055**	3.413**	0.210**	1462.37**
Error	108	0.001	0.009	0.001	0.001	0.001	0.05	0.041	133.41

** Significant at 1% level of probability.

Table 4. Estimate of general combining ability effect of parents for quality and yield

Parent	Total phenol content	Total soluble solid	Non-reducing sugar	Reducing sugar	Total sugar	Ascorbic acid	Dry matter content	Yield per hectare
Punjab Sadabahar	0.118 **	0.007	-0.009 **	0.034 **	0.007	-1.124 **	-0.136 *	-11.814 **
NDB.Sel-19-1	0.060 **	0.187 **	-0.038 **	0.027 **	-0.016	0.457 **	-0.028	-15.626 **
Pant Samrat	0.059 **	0.032	-0.018 **	0.064 **	0.063 **	-0.306 **	-0.002	-0.511
NDBSel. -16-1	-0.090 **	-0.070 **	0.029 **	0.001	0.048 **	0.238 **	-0.202 **	-9.134 **
NDB-2	0.004	0.133 **	0.049 **	0.008	0.028 **	-0.326 **	0.126 *	-16.665 **
NDB 3	0.019 **	-0.120 **	-0.009 **	0.001	-0.005	0.775 **	-0.043	13.407 **
Pusa Kranti	-0.050 **	-0.141 **	-0.003	0.007	0.014	0.274 **	0.028	-11.705**
Pusa Purple Long	-0.042 **	0.099 **	0.006	-0.078 **	-0.068 **	-0.12	0.132 *	2.317
Arka Nidhi	-0.063 **	-0.163 **	0.008 **	-0.042 **	-0.032 **	0.347 **	0.184 **	7.090 *
Pant Rituraj	-0.014 *	0.035	-0.015 **	-0.020 **	-0.040 **	-0.215 **	-0.059	42.639 **
SE(G1)	0.014 **	0.059 **	0.007 **	0.016 **	0.020 **	0.138 **	0.125 **	7.155 **
SE(Gi-Gj)	0.021 **	0.088 **	0.010 **	0.023 **	0.029 **	0.206 **	0.186 **	10.667 **
Best parents based on *per se* performance and *gca* effects	Punjab Sadabahar NDB 3	NDB-2 NDB.Sel-19-1	NDB-2 NDB.Sel-16-1	NDB.Sel-19-1Punjab Sadabahar	NDB-2 NDB.Sel-16-1	NDB.Sel-16-1 Pusa Kranti	Pusa Purple Long NDB-2	NDB 3 Arka Nidhi

** Significant at 1% level of probability.

Among 45 crosses, the NDB-3 × Arka Nidhi was best specific combiner for reducing sugar, total sugar and dry matter content, respectively. Pant Samrat × Pusa Purple Long was found good specific combiner for TPC, NDB. Sel-19-1 × NDB-3 was found good specific combiner for total soluble solid, Punjab Sadabahar × Pusa Kranti was found good specific combiner for non-reducing sugar, NDB.Sel-19-1 × Pusa Purple Long was found good specific combiner for ascorbic acid, Pusa Purple Long × Pant Rituraj was found good specific combiner for yield per hectare, when considered on the basis of *per se* performance and positive *sca* effects (Table 5). Genotypes and environment interaction were highly significant for the entire studied trait except for the fruit length to width ratio. These results indicated that both parents and offspring were highly influenced by the environment for all traits. Eggplants are mostly self-pollinated crops that have fixed alleles and genetic variation is also limited among cultivated varieties. Under this situation, different underexploited variabilities in different gene pools can contribute useful genes to improve existing cultivars. Specific combining ability (SCA) is the deviation from the assumed performance depending on general combining ability. Specific combining ability is regulated by non-additive gene action. It is considered an important criterion to evaluate hybrids. Positive and significant SCA values were usually related with hybrids in which leastwise one parent was well combined. Similar finding was reported by (30-36).

The range of heterosis over better parent varied between -24.32 to 52.65 % for TPC, -22.57 to 13.63 % for total soluble solid, -52.53 to 72.15 % for non-reducing sugar, -44.83 to 60.08 % for reducing sugar, -36.69 to 47.83 % for total sugar, -42.81 to 35.69 % for ascorbic acid, -17.79 to 19.23% for dry matter content and -17.56 to 72.26 % for yield. The range of heterosis over mid parent varied between -15.31 to 55.19 % for TPC, -19.24 to 22.49 % for total soluble solid, -45.98 to 78.67 % for non-reducing sugar, -34.78 to 64.95 % for reducing sugar, -30.93 to 57.39 % for total sugar, -36.36 to 42.73 % for ascorbic acid, -11.58 to 22.23 % for dry matter content and -11.93 to 72.74 % for yield. The highest magnitude of heterosis over better parent for TPC was recorded in cross combination Pusa Kranti × Pant Rituraj (52.65 %) followed by NDB.Sel.-16-1 × Pant Rituraj (27.44 %) and NDB. Sel.- 19-1 × NDB-2 (24.84 %), whereas cross combination Pusa Kranti × Pant Rituraj (55.19 %) followed by Pant Samrat × Pusa Purple Long (36.95 %) and Pant Samrat × Pant Rituraj (35.56 %) was found better over mid parent. The maximum heterosis over better parent was found in cross combination NDB.Sel-19-1 × NDB. Sel. -16-1 (13.63 %) followed by NDB Sel-19-1 × Pusa Purple Long (12.42 %) and NDB.Sel-19-1 × NDB-3 (12.04 %) for total soluble solid, whereas cross NDB.Sel-19-1 × NDB-3 (22.49 %) followed by NDB.Sel-19-1 × NDB Sel. -16-1 (17.60 %) and NDB Sel. -16-1 × NDB-3 (13.23 %) was found over mid parent. The outmost heterosis over better parent was found in cross combination Pant Samrat × Arka Nidhi (72.15 %) followed by Pant Samrat × Pusa Purple Long (34.24 %) and Punjab Sadabahar × Pusa Kranti (33.33 %) for non- reducing sugar, whereas cross Pant Samrat × Arka Nidhi (78.67 %) followed by Pant Samrat × Pusa Purple Long (59.04 %) and NDB-3 × Arka Nidhi (48.48 %) was found over mid parent. The highest heterosis over better parent was found in cross combination NDB-3× Arka Nidhi (60.08 %) followed by NDB

Table 5. Ranking of three desirable specific combiners on the basis of *per se* performance and *sca* effect for quality and yield

Character	Desirable parents according to per Sc performance	Good specific combiners	Best parents based on per se performance & sca effects
Total phenol content	Pant Samrat × Pusa Purple Long NDB.Sel-19-1 × NDB-2 Punjab Sadabahar × Pusa Purple Long	Pant Samrat × Pusa Purple Long Pusa Kranti × Pant Rituraj NDBSel-16-1 × NDB-3	Pant Samrat × Pusa Purple Long
Total soluble solid	NDB.Sel-19-1 × NDBSel-16-1 NDB.Sel-19-1 × Pusa Purple Long NDB.Sel-19-1 × NDB-3	NDB.Sel-19-1 × NDBSel-16-1 NDB.Sel-19-1 × NDB-3 Pusa Kranti × Pusa Purple Long	NDB.Sel-19-1 × NDB-3
Non-reducing sugar	NDB.Sel-19-1 × NDB-2 Punjab Sadabahar × Pusa Kranti Pusa Kranti × Pusa Purple Long	Punjab Sadabahar × Pusa Kranti Pusa Kranti × Pusa Purple Long Pant Samrat × Pusa Purple Long	Punjab Sadabahar × Pusa Kranti Pusa Kranti × Pusa Purple Long
Reducing sugar	NDB-3 × Pusa Kranti Punjab Sadabahar × Pant Samrat NDB-3 × Arka Nidhi	NDB-3 × Arka Nidhi Pusa Kranti × Pusa Purple Long NDB-3 × Pusa Kranti	NDB-3 × Arka Nidhi NDB-3 × Pusa Kranti
Total sugar	Pusa Kranti × Pusa Purple Long NDB-3 × Arka Nidhi Punjab Sadabahar × Pant Samrat	Pusa Kranti × Pusa Purple Long NDB-3 × Arka Nidhi Pusa Purple Long × Pant Rituraj	Pusa Kranti × Pusa Purple Long NDB-3 × Arka Nidhi
Ascorbic acid	NDB.Sel-19-1 × Pusa Purple Long NDB.Sel-19-1 × Pant Samrat NDBSel-16-1 × NDB-3	Punjab Sadabahar × Pusa Purple Long Punjab Sadabahar × Pusa Kranti NDB.Sel-19-1 × Pusa Purple Long	NDB.Sel-19-1 × Pusa Purple Long
Dry matter content	NDB-3 × Arka Nidhi Pant Samrat × NDB-2 NDB-2 × Arka Nidhi	NDB-3 × Arka Nidhi NDBSel-16-1 × Arka Nidhi Pant Samrat × NDB-2	NDB-3 × Arka Nidhi Pant Samrat × NDB-2
Yield per hectare	Pusa Purple Long × Pant Rituraj Arka Nidhi × Pant Rituraj Punjab Sadabahar × Pant Rituraj	NDBSel-16-1 × Pusa Kranti Pusa Purple Long × Pant Rituraj Punjab Sadabahar × Pant Rituraj	Pusa Purple Long × Pant Rituraj Punjab Sadabahar × Pant Rituraj

-3 × Pusa Kranti (57.36 %) and Pusa Purple Long × Pant Rituraj (52.60 %) for reducing sugar, whereas cross Pusa Kranti × Pusa Purple Long (64.95 %) followed by NDB-3 × Arka Nidhi (62.28 %) and NDB-3 × Pusa Kranti (61.63 %) was found over mid parent. The maximum heterosis recorded for total sugar in the cross-combination NDB-3 × Arka Nidhi (47.83 %) followed by Pusa Kranti × Pusa Purple Long (44.92 %) and Pusa Purple Long × Pant Rituraj (27.49 %) over better parent and NDB-3 × Arka Nidhi (57.39 %) followed by Pusa Kranti × Pusa Purple Long (54.76 %) and Pusa Purple Long × Pant Rituraj (39.74 %) for over mid parent. The highest heterosis recorded for ascorbic acid in the cross-combination NDB.Sel-19-1 × Pusa Purple Long (35.69 %) followed by NDB.Sel-19-1 × NDB-3 (32.26 %) and Punjab Sadabahar × Pusa Purple Long (24.05 %) over better parent and NDB.Sel-19-1 × NDB-3 (42.73 %) followed by Punjab Sadabahar × Pusa Purple Long (42.53 %) and NDB.Sel-19-1 × Pusa Purple Long (37.41 %) for over mid parent. The maximum heterosis recorded for dry matter content in the cross-combination NDB-3 × Arka Nidhi (19.23 %) followed by NDB.Sel-16-1 × Arka Nidhi (11.82 %) and NDB-3 × Pusa Kranti (10.24 %) over better parent and NDB-3 × Arka Nidhi (22.23 %) followed by NDB.Sel-16-1 × Arka Nidhi (13.56 %) and NDB-3 × Pusa Kranti (13.26 %) for over mid parent. The highest heterosis over better parent was recorded in Punjab Sadabahar × Pant Rituraj (72.26 %) followed by Pusa Purple Long × Pant Rituraj (63.36 %) and NDB-2 × Pant Rituraj (55.57 %) for yield. Whereas over mid-parent cross combination Pusa Purple Long × Pant Rituraj (72.74%), Punjab Sadabahar × Pant Rituraj (72.63 %) and Arka Nidhi × Pant Rituraj (65.32%) exhibited maximum heterosis (Table 6). It is pertinent to note that some hybrids of low x low and low x high yielding parents manifested relatively high heterobeltiosis while some hybrids involving high x high yielding parents exhibited low heterobeltiosis. The probable explanation for this type of behaviour is that poor-yielding parents might have different constellations of genes with complementary action when brought together in a hybrid combination. It is, therefore, desirable to select hybrid based on their mean performance rather than heterotic effect. Stable hybrids could be directly used for yield improvement. The stable component traits always result in a stable fruit yield per plant. The challenge of finding a hybrid with stability for all the traits, showing the scope for the inclusion of more environments for future analysis. Developing high-yielding crosses, suitable for farming conditions of the region combined with high market preference in the concerned area is necessary while breeding for fruit yield in brinjal. The results also conform with those obtained by (37-45). Such combinations are expected to throw better segregants for fruit yield and yield attributes in the subsequent generations which can be exploited effectively for improvement of brinjal.

Conclusion

The analysis of variance showed significant difference due to treatments for all the characters except non-reducing, ascorbic acid and dry matter content for parent *vs* F_1s. The *gca* variance were higher than the *sca* variance except for non-reducing, reducing sugar, total sugar, ascorbic acid, dry matter content. The gca variance were higher than sca variance for yield character so it indicates the predominance of non-additive gene effect. On the basis of *per se* performance and significant *gca* effects NDB-3 was good general combiner for yield. Among 45 crosses, Pusa Purple Long × Pant Rituraj was found good specific combiner for yield. The range of heterosis over better parent

Table 6. Best three crosses selected on the basis of heterosis for quality and yield

Character	Heterosis over BP		Heterosis over MP		Range over	
	Crosses	%Heterosis	Crosses	%Heterosis	BP	MP
Total phenol content	Pusa Kranti × Pant Rituraj	52.65	Pusa Kranti × Pant Rituraj	55.19	-24.32 – 52.65	-15.31 – 55.19
	NDBSel. -16-1 × Pant Rituraj	27.44	Pant Samrat × Pusa Purplle Long	36.95		
	NDB.Sel-19-1 × NDB-2	24.84	Pant Samrat × Pant Rituraj	35.56		
Total soluble solid	NDB.Sel-19-1 × NDBSel. -16-1	13.63	NDB.Sel-19-1 × NDB 3	22.49	-22.57 – 13.63	-19.24 – 22.49
	NDB.Sel-19-1 × Pusa Purple Long	12.42	NDB.Sel-19-1 × NDBSel. -16-1	17.6		
	NDB.Sel-19-1 × NDB 3	12.04	NDBSel. -16-1 × NDB 3	13.23		
Non-reducing sugar	Pant Samrat × Arka Nidhi	72.15	Pant Samrat × Arka Nidhi	78.67	-52.53 – 72.15	-45.98 – 78.67
	Pant Samrat × Pusa Purple Long	34.24	Pant Samrat × Pusa Purple Long	59.04		
	Punjab Sadabahar × Pusa Kranti	33.33	NDB 3 × Arka Nidhi	48.48		
Reducing sugar	NDB 3 × Arka Nidhi	60.08	Pusa Kranti × Pusa Purple Long	64.95	-44.83 – 60.08	-34.78 – 64.95
	NDB 3 × Pusa Kranti	57.36	NDB 3 × Arka Nidhi	62.28		
	Pusa Purple Long × Pant Rituraj	52.6	NDB 3 × Pusa Kranti	61.63		
Total sugar	NDB 3 × Arka Nidhi	47.83	NDB 3 × Arka Nidhi	57.39	-36.69 – 47.83	-30.93 – 57.39
	Pusa Kranti × Pusa Purple Long	44.92	Pusa Kranti × Pusa Purple Long	54.76		
	Pusa Purple Long × Pant Rituraj	27.49	Pusa Purple Long × Pant Rituraj	39.74		
Ascorbic acid	NDB.Sel-19-1 × Pusa Purple Long	35.69	NDB.Sel-19-1 × NDB 3	42.73	-42.81 – 35.69	-36.36 – 42.73
	NDB.Sel-19-1 × NDB 3	32.26	Punjab Sadabahar × Pusa Purple Long	42.53		
	Punjab Sadabahar × Pusa Purple Long	24.05	NDB.Sel-19-1 × Pusa Purple Long	37.41		
Dry matter content	NDB 3 × Arka Nidhi	19.23	NDB 3 × Arka Nidhi	22.23	-17.79 – 19.23	-11.58 – 22.23
	NDBSel. -16-1 × Arka Nidhi	11.82	NDBSel. -16-1 × Arka Nidhi	13.56		
	NDB 3 × Pusa Kranti	10.24	NDB 3 × Pusa Kranti	13.26		
Yield per hectare	Punjab Sadabahar × Pant Rituraj	72.26	Pusa Purple Long × Pant Rituraj	72.74	-17.56 – 72.26	-11.93 – 72.74
	Pusa Purple Long × Pant Rituraj	63.36	Punjab Sadabahar × Pant Rituraj	72.63		
	NDB-2 × Pant Rituraj	55.57	Arka Nidhi × Pant Rituraj	65.32		

** Significant at 1% level of probability, BP - Better parent, MP - Mid parent varied between -17.56 to 72.26 % for yield. The range of heterosis over mid parent varied between -11.93 to 72.74 % for yield. On the basis of results, Punjab Sadabahar, NDB-3 and NDB-2 may be used for hybridization. The crosses Punjab Sadabahar × Pant Rituraj and NDB-3 × Pusa Kranti may be tested for further yield and quality traits under different agro-climatic conditions in commercial exploitation of hybrid vigour. On the basis of the above findings, it can be concluded that improvement in brinjal for TPC, total soluble solid, non-reducing sugar, reducing sugar, total sugar, ascorbic acid, dry matter content may be brought out through hybridization followed by recurrent selection and significant specific hybrid for yield would be useful to researchers and needs confirmation. The superior crosses attempted through half-diallel design utilizing local germplasm of brinjal on the basis of significant heterosis over better parent and sca effects can be further exploited for commercial cultivation after multilocation testing.

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Authors' contributions

LY designing of experiments, carried out the field experiment and drafted the manuscript. LY, BS, AJ conceptualization of research. AJ, DKU analysis of the data and interpretation. LY, AJ, CNR, DKU preparation of the final manuscript All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

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