A-6204
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RESEARCH ARTICLE Indian Journal of Agricultural Research

Analysis of Heterosis and Stability in Brinjal at Multi-locations of Gujarat for Yield and its Attributing Traits

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10.18805/IJARe.A-6204

ABSTRACT

Background: Brinjal is the important vegetable crop. The extensive use of heterosis in vegetable crops has led to the creation of numerous high-yielding hybrid cultivars. Newly developed hybrids should also be tested across environments to develop region specific hybrids or hybrid for all the regions.

Methods: The purpose of the present experiment was to develop region-specific brinjal (*Solanum melongena* L.) hybrids through line × tester design and to gather information on heterosis and stability for fruit yield and associated characters at multiple locations of *viz*., Sardarkrushinagar, Jagudan and Bhiloda under the jurisdiction of S.D.A.U. in late *rabi* 2021–2022.

Result: There were noticeable genetic differences in the material for the majority of the traits. Several crosses were identified which showed desirable heterosis for at least one yield component in individual and pooled over locations. Fruit yield per plant is the most important trait. Hybrid 'ISD-006 × GOB-5' showed the highest fruit yield and maximum standard heterosis for fruit yield per plant, fruit girth, fruit weight, total soluble solids and chlorophyll content index. The interaction of G × E was highly significant for the majority of characters suggesting the differential response of experimental material to the varied locations. Stability analysis suggested 'ISD-006 × GAB-6', 'JDNB-16-1 × GOB-1' and 'ABSR-2 × GAB-6' as the top three stable crosses for fruit yield per plant. Overall, 'ISD-006 × GRB-5' appeared to be an outstanding cross for fruit yield and its attributing traits in terms of heterobeltiosis and standard heterosis in individual and pooled environments. As well as it was found to be average stable for four major traits and stable in favourable environments for fruit weight and yield per plant. Also, incorporating hybrids identified in this experiment might potentially result in transgressive segregants in brinjal.

Key words: G × E, Heterosis, Line × Tester, *Solanum melongena*.

INTRODUCTION

Vegetables, such as brinjal, are a natural source of protective food due to their roughage, vitamins and minerals. Brinjal is self-pollinating and originated in India, allowing breeders to use heterosis breeding to improve yield and economic features. The extensive use of heterosis in vegetable crops has led to the creation of numerous high-yielding hybrid cultivars. Newly developed hybrids should be more economical than standard hybrids and they should be performed similarly across multiple regions to make them popular; or, specific hybrids should perform better than average in specific regions to make them recommended for that region. This information can be obtained through analysis of genotype × environment interactions. Eberhart and Russel (1966) provided a clear-cut idea to test materials and select stable genotypes over environments. These details can serve as a reference for best practices to increase germplasm potential, ultimately benefiting heterosis in brinjal hybridization.

MATERIALS AND METHODS

The materials were comprised of 8 lines ['Arka Komal', 'Ph-6', 'Ph-9', 'PPL', 'JDNB-16-1', 'ISD-006', 'CO2' and 'ABSR-2'], 6 testers ['GOB-1', 'GAOB-2', 'GAB-6', 'GRB-5', 'Arka Harshita' and 'P. Anupam'], 48 F_1s and standard checks ['GJBH-4' (standard check 1) and 'GABH-3' (Standard check 2)]. The hybrids were prepared by adopting line × tester mating design during *kharif* 2021. The evaluation programme was carried out using RBD with three replications during late *rabi* 2021-22 at three different locations, *viz*. (i) Horticulture Instructional Farm, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, District: Banaskantha (E_1) (ii) Seed Spices Research Station, S.D.A.U., Jagudan, District: Mehsana (E_2) (iii) Maize Research Station, S.D.A.U., Bhiloda,

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How to cite this article: Joshi, D.P., Patel, N.B., Patel, A.M., Zala, H.N. and Prajapati, N.N. (2024). Analysis of Heterosis and Stability in Brinjal at Multi-locations of Gujarat for Yield and its Attributing Traits. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.A-6204.

Submitted: 02-01-2024 **Accepted:** 05-04-2024 **Online:** 03-06-2024

District: Aravalli (E_3). Five sample plants from each genotype in each replication were marked for recording 14 characters (days to opening of first flower, days to first picking, fruit pedicel length, fruit length, fruit girth, fruit shape index, fruit weight, number of fruits per plant, number of primary branches per plant, plant height, fruit yield per plant, plant spread, total soluble solids and chlorophyll content index) and average data were used for applying statistical procedures. Standard statistical methods were applied *viz*., pooled analysis of variance (ANOVA) estimation (Comstock and Robinson, 1952); percent heterosis estimation (Fonseca and Patterson,1968) and stability assessment (Eberhart and Russel, 1966).

RESULTS AND DISCUSSION

The ANOVA of individual and pooled environments showed noticeable genetic differences in the material for the majority of the traits (excluding total soluble solids for genotypes at Jagudan). Behaviour of genotypes was different in different locations for the majority of the traits (excluding days to first

Table 1: Pooled over locations analysis of top hybrids in terms of desired standard heterosis; with their heterobeltiosis and mean data for 14 traits in Brinjal.

Traits	Cross	Standard heterosis over GJBH-4 (%)	Standard heterosis over GABH-3 (%)	Heterobeltiosis (%)	Pooled mean value
Days to opening of first flower	ISD-006 × GRB-5	3.72	5.69	-6.57*	80.56
Days to first picking	ISD-006 × GRB-5	3.02	1.02	-4.33*	98.33
Fruit pedicel length	Arka Komal × GOB-1	10.05	23.50**	30.94**	5.22 mm
	ISD-006 × Arka Harshita	18.06**	32.49**	22.09**	5.60 mm
	PPL × GAOB-2	7.59	20.74**	12.74	5.10 mm
Fruit length	PPL × Arka Harshita	25.20**	61.64**	-13.35**	14.62 cm
	Arka Komal × P. Anupam	22.29**	57.89**	10.81*	14.28 cm
	PPL × GAB-6	17.52**	51.73**	-18.66**	13.73 cm
Fruit girth	Ph-9 × GOB-1	61.34**	20.80**	2.49	22.40 cm
	ISD-006 × GRB-5	47.83**	10.68*	-13.56**	20.52 cm
	Ph-9 × GRB-5	47.71**	10.59*	-6.18	20.51 cm
Fruit shape index	Arka Komal × P. Anupam	77.65**	210.27**	5.35	1.51
	PPL × Arka Harshita	66.27**	190.41**	-14.86**	1.41
	Arka Komal × GAB-6	60.78**	180.82**	-4.65	1.37
Fruit weight	ISD-006 × GRB-5	51.88**	52.13**	19.37**	134.85 g
	ISD-006 × GAOB-2	30.26**	30.48**	2.38	115.66 g
	ISD-006 × GOB-1	28.26**	28.47**	0.81	113.88 g
Number of fruits per plant	ABSR-2 × GAB-6	157.81**	152.66**	55.47**	77.38
	ABSR-2 × Arka Harshita	118.61**	114.24**	31.83*	62.22
	PPL × P. Anupam	116.72**	112.40**	16.39	61.69
No. of primary branches per plant	-	-	-	-	-
Plant height	JDNB-16-1 × GOB-1	14.62*	5.58	22.37**	81.47 cm
	ISD-006 × GOB-1	8.87	0.28	16.23*	77.38 cm
	CO2 × GOB-1	6.76	-1.66	13.97*	75.88 cm
Plant spread	JDNB-16-1 × GOB-1	18.54*	7.98	16.14*	97.87 cm
	CO2 × GRB-5	8.51	-1.16	17.03*	89.58 cm
	ISD-006 × GAOB-2	12.52	2.49	16.24*	92.89 cm
Total soluble solids	Ph-6 × P. Anupam	10.47**	18.40**	8.99*	6.54 °B
	ISD-006 × GRB-5	9.79**	17.67**	3.50	6.50 °B
	Ph-6 × GRB-5	7.32	15.02**	1.17	6.36 °B
Chlorophyll content index	Ph-9 × GOB-1	12.41	58.73**	5.33	77.42 CCI
	JDNB-16-1 × GAB-6	10.35	55.83**	-1.77	76.00 CCI
	Ph-9 × GAB-6	8.86	53.72**	14.53	74.97 CCI
Fruit yield per plant	ISD-006 × GRB-5	47.36*	32.42	70.15**	3733.38 g
	ISD-006 × GOB-1	31.47	18.14	60.94**	3330.88 g
	ABSR-2 × Arka Harshita	15.88	4.13	57.93*	2935.83 g

**,* are the level of significance at 1% and 5%, respectively picking and total soluble solids). Parents *vs.* hybrids interaction proved the existence of overall heterosis at three locations for the majority of the characters. Also, considerable variations among the environments were observed for the majority of the traits (excluding total soluble solids).

Positive heterotic effects were desirable for all the traits (excluding days to first flower and first picking). For a particular trait, some hybrids showed higher heterotic effects while others showed lower, which was due to the variation in the genetic nature of the parents. Out of 48 F_1 hybrids studied, top hybrids based on a pooled analysis of 14 traits for desired standard heterosis along with heterobeltiosis and mean value are displayed in Table 1. Also, 48 hybrids' heterobeltiosis and economic heterosis for fruit yield per plant over the pooled environments are shown in Fig 1. For days to opening of first flower and days to first picking, 'ISD-006 × GRB-5' was found desirable in terms of heterobeltiosis. For fruit pedicel length 'Arka Komal × GOB-1', 'ISD-006 × Arka Harshita' and 'PPL × GAOB-2' were the hybrids of choice. 'PPL × Arka Harshita' and 'Arka Komal × P. Anupam' were the top hybrids for fruit length and fruit shape index. 'Ph-9 × GOB-1', 'ISD-006 × GRB-5' and 'Ph-9 × GRB-5' showed significant desirable standard heterosis for fruit girth. Being an important trait, fruit weight showed 'ISD-006 × GRB-5', 'ISD-006 × GAOB-2' and 'ISD-006 × GOB-1' as the top desired hybrids. There were also sufficient desirable hybrids obtained for a number of fruits per plant, but the same wasn't noticed for a number of primary branches per plant. 'JDNB-16-1 × GOB-1' was the top significant hybrid for plant spread and plant height. Total soluble solids and chlorophyll content index also showed desirable hybrids in terms of standard heterosis and heterobeltiosis.

The yield of fruits per plant is the most important plant character. The hybrid 'ISD-006 × GRB-5' was the hybrid of choice for this trait. It showed high standard heterosis over 'GJBH-4', significant heterobeltiosis in the desired direction and high mean fruit yield. In case of individual environments for fruit yield per plant; 'ISD-006 × GOB-1', 'CO2 × GOB-1', 'Arka Komal × GRB-5', 'PPL × P. Anupam' and 'ISD-006 × GRB-5' at Sardarkrushinagar; 'ABSR-2 × GAB-6', 'Ph-9 × Arka Harshita', 'ABSR-2 × Arka Harshita', 'ISD-006 × GAB-6' and 'ISD-006 × GRB-5' at Jagudan and 'ISD-006 × GRB-5' at Bhiloda showed desirable standard heterosis.

These hybrids showed desirable heterosis for at least one yield component. Almost the same trend was noticed by Saikia *et al.* (2019) for fruit pedicel length; by Makani *et al*. (2013) regarding longer fruit and fruit girth; Chaudhari *et al.* (2020) regarding number of fruits per plant and fruit yield per plant; Rani *et al.* (2018) regarding plant height and Singh and Chaudhary (2018) regarding TSS and chlorophyll content index.

Stability ANOVA (Table 2) showed that the genotypes were highly significant and majority of the traits were highly affected by the interaction of genotypes × environments (G × E). But genotypes showed consistent behaviour for days to first picking and total soluble solids over the locations, which prevented their further stability analysis. Singh and Chaudhary (2018) and Bhushan and Samnotra (2017) found the same trends in brinjal. Both unpredictable and predictable components affected the stability of the majority traits, which were noticeable by the presence of significant interaction of pooled deviation (non-linear component) with pooled error. Prasad *et al*. (2002) and Sivakumar *et al.* (2017) derived the same type of conclusion.

Regression coefficient (b_i), mean performance and squared deviation from linear regression (S^2d_i) are the

Checkerboard of 1 to 48 hybrids developed through L × T mating

Testers \ Lines	Arka Komal	Ph-6	Ph-9	PPL	JDNB-16-1	ISD-006	CO2	ABSR-2
GOB-1	1	7	13	19	25	31	37	43
GAOB-2	2	8	14	20	26	32	38	44
GAB-6	3	9	15	21	27	33	39	45
GRB-5	4	10	16	22	28	34	40	46
Arka Harshita	5	11	17	23	29	35	41	47
P. Anupam	6	12	18	24	30	36	42	48

Fig 1: Standard heterosis and heterobeltiosis for fruit yield per plant for pooled over environments.

Table 2: Stability ANOVA over the environment for different traits of brinjal.

Characters	Genotype [61]	Environment [2]	G × E [126]	Env. + (G × E) [124]	Env. (Lin) [1]	G × E (Lin) [61]	Pooled deviation [62]	Pooled error [366]
Days to opening of first flower	40.168**$^{++}$	2857.034**$^{++}$	9.000**$^{++}$	54.936**$^{++}$	5714.068**$^{++}$	13.095**$^{++}$	4.826	6.318
Days to first picking	24.021**$^{++}$	2301.100**$^{++}$	6.390^{++}	43.402**$^{++}$	4602.201**$^{++}$	9.035*$^{++}$	3.684	5.945
Fruit pedicel length	0.707**$^{++}$	0.970**++	0.135**	0.148**	1.941**$^{++}$	0.102**	0.165**	0.065
Fruit length	14.523**$^{++}$	4.029**$^{++}$	0.587**	0.642**	8.058**$^{++}$	0.463*	0.698**	0.319
Fruit girth	33.084**$^{++}$	14.722**$^{++}$	1.640**	1.851**$^{+}$	29.445**$^{++}$	2.033**$^{+}$	1.226*	0.893
Fruit shape index	0.316**$^{++}$	0.114**$^{++}$	0.008**$^{+}$	0.009**$^{++}$	0.229**$^{++}$	0.011**$^{++}$	0.005**	0.003
Fruit weight	1585.399**$^{++}$	4523.498**$^{++}$	107.653**$^{++}$	178.876**$^{++}$	9046.996**$^{++}$	155.935**$^{++}$	58.413**	29.715
Number of fruits per plant	463.358**$^{++}$	11468.267**$^{++}$	76.206**	259.949**$^{++}$	22936.535**$^{++}$	73.135**	77.998**	9.118
No. of primary branches per plant	0.301**	27.750**$^{++}$	0.195**	0.639**$^{++}$	55.500**$^{++}$	0.188**	0.199**	0.113
Plant height	121.320**$^{++}$	10661.978**$^{++}$	33.136*	204.569**$^{++}$	21323.957**$^{++}$	40.836**$^{+}$	25.026	24.339
Fruit yield per plant	837488.896**$^{++}$	69199842.741**$^{++}$	339217.696**	1449872.938**$^{++}$	138399685.482**$^{++}$	277331.434**	394634.538**	46959.219
Plant spread	151.693**$^{++}$	4971.958**$^{++}$	57.587**	136.851**$^{++}$	9943.917**$^{++}$	68.141**	46.275	39.246
Total soluble solids	0.201**$^{++}$	0.137	0.080	0.081	0.275	0.080	0.079	0.089
Chlorophyll content index	179.265**$^{++}$	5748.488**$^{++}$	49.588**	141.506**$^{++}$	11496.976**$^{++}$	34.132**	63.995**	7.667

**,* are the level of significance at 1% and 5%, respectively when tested with pooled error mean square for all the sources.

$^{++}$, $^{+}$ are the level of significance at 1% and 5%, respectively when tested with pooled deviation mean square for all the sources.

Figures in parenthesis "[ ]" showing degree of freedom of each source of variation.

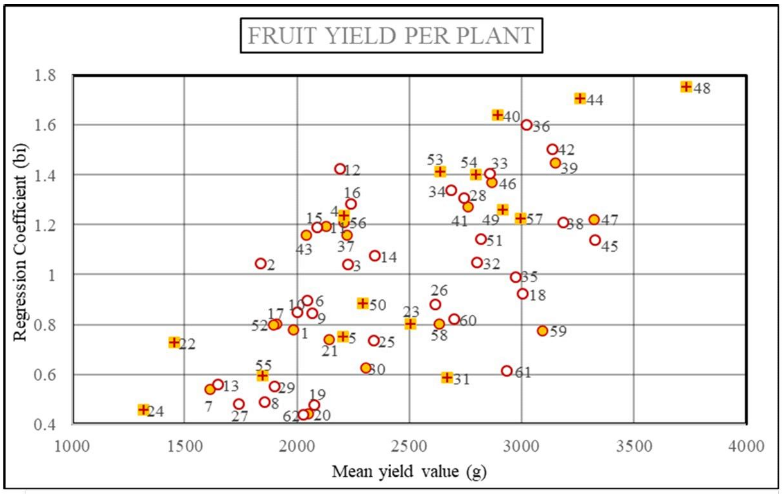
Table 3: The top three stable parents and crosses, ranked according to traits, for both general and specific environments.

	Average stable genotypes			Suitable for favourable environment		Suitable for unfavourable environment/poor condition	
	Parents		Crosses	Parents	Crosses	Parents	Crosses
	Lines	Testers					
Days to opening of first flower	JDNB-16-1	GAOB-2	Ph-9 × GAOB-2	PPL	PPL × P. Anupam	Arka Harshita	Ph-9 × Arka Harshita
	Ph-9	P. Anupam	JDNB-16-1 × GOB-1	-	Ph-6 × Arka Harshita	GOB-1	PPL × GOB-1
	-	-	ISD-006 × GRB-5	-	Arka Komal × P. Anupam	-	PPL × Arka Harshita
Fruit pedicel length	JDNB-16-1	-	Ph-6 × GAB-6	ISD-006	ISD-006 × Arka Harshita	PPL	PPL × P. Anupam
	-	-	ISD-006 × GAOB-2	-	Arka Komal × GOB-1	-	Ph-9 × Arka Harshita
	-	-	Arka Komal × Arka Harshita	-	PPL × GAOB-2	-	PPL × GAB-6
Fruit length	Arka Komal	P. Anupam	PPL × GAB-6	-	PPL × P. Anupam	PPL	PPL × Arka Harshita
	-	-	Arka Komal × GAB-6	-	JDNB-16-1 × P. Anupam	-	CO2 × Arka Harshita
	-	-	ISD-006 × Arka Harshita	-	-	-	CO2 × GAB-6
Fruit girth	-	GRB-5	ISD-006 × GRB-5	JDNB-16-1	CO2 × GRB-5	GOB-1	Ph-9 × GOB-1
	-	GAB-6	ISD-006 × GAOB-2	-	Arka Komal × GAOB-2	-	ISD-006 × GOB-1
	-	-	Ph-9 × GAOB-2	-	PPL × GAOB-2	-	ABSR-2 × GAOB-2
Fruit shape index	PPL	-	Arka Komal × P. Anupam	Arka Komal	PPL × P. Anupam	-	CO2 × GAB-6
	GAB-6	-	CO2 × Arka Harshita	Arka Harshita	Arka Komal ×	Arka Harshita	- Ph-6 × P. Anupam
	-	-	PPL × GAB-6	P. Anupam	CO2 × P. Anupam	-	PPL × GOB-1
Fruit weight	-	GAOB-2	ISD-006 × GOB-1	-	ISD-006 × GRB-5	GOB-1	ISD-006 × GAB-6
	-	GRB-5	JDNB-16-1 × GOB-1	-	ISD-006 × GAOB-2	-	Ph-6 × GRB-5
	-	-	PPL × GOB-1	-	ISD-006 × Arka Harshita	-	-
Number of fruits per plant	-	-	ABSR-2 × GAB-6	GAB-6	ABSR-2 × GOB-1	-	-
	-	-	Ph-6 × GAB-6	-	JDNB-16-1 × P. Anupam	-	-
	-	-	Arka Komal × GAB-6	-	ISD-006 × GAB-6	-	-
Number of primary branches per plant	-	P. Anupam	PPL × GAB-6	GAOB-2	CO2 × GAB-6	-	Ph-9 × P. Anupam
	-	GOB-1	ABSR-2 × GRB-5	Arka Komal	Arka Komal × GRB-5	-	ISD-006 × GAOB-2
	-	GAB-6	ABSR-2 × GAOB-2	-	Arka Komal × GAOB-2	-	PPL × GRB-5
Plant height	Ph-6	GAB-6	JDNB-16-1 × GAB-6	GRB-5	JDNB-16-1 × GOB-1	-	CO2 × GOB-1
	-	GAOB-2	ISD-006 × GOB-1	-	JDNB-16-1 × GRB-5	-	PPL × GRB-5
	-	-	ISD-006 × GRB-5	-	ISD-006 × GAOB-2	-	PPL × GAB-6
Fruit yield per plant	-	-	ISD-006 × GAB-6	-	ISD-006 × GRB-5	-	Ph-9 × Arka Harshita
	-	-	JDNB-16-1 × GOB-1	-	JDNB-16-1 × P. Anupam	-	Ph-6 × GAB-6
	-	-	ABSR-2 × GAB-6	-	ABSR-2 × GOB-1	-	
Plant spread	JDNB-16-1	GAB-6	ISD-006 × GAOB-2	-	Arka Komal × GAOB-2	-	ISD-006 × GAB-6
	-	GOB-1	ISD-006 × GOB-1	-	Ph-9 × Arka Harshita	-	ISD-006 × Arka Harshita
	-	P. Anupam	ISD-006 × GRB-5	-	Arka Komal × GOB-1	-	JDNB-16-1 × GAOB-2
Chlorophyll content index	-	GOB-1	JDNB-16-1 × GAB-6	Ph-9	Ph-6 × GOB-1	-	PPL × GAB-6
	-	-	CO2 × GOB-1	-	PPL × GOB-1	-	JDNB-16-1 × GOB-1
	-	-	ISD-006 × GAB-6	-	Ph-6 × Arka Harshita	-	

stability parameters which were calculated for 12 characters for hybrids and parents to analyse the stability over the locations. Table 3 is showing the analysed results with the top three parents and hybrids for each character in each condition of stability.

The stable genotypes should be used for various breeding activities (Rai *et al*., 2000). The criteria of Mehra and Ramanujam (1978) were used for the stability assessment. The 'b_i' was considered as a level of response of a genotype and 'S^2d_i' was treated as a level of stability. The non-significant regression coefficient was treated as a unity. Non-significant S^2d_i was the sign of "minimum deviation" *i.e*., zero. Hence, the genotypes which possess the above values with desirable higher mean were considered stable. A desirable higher mean with significantly higher b_i than unity and non-significant S^2d_i was considered as less than average stable (adaptable to favourable environments but sensitive to environmental changes). Also, a condition of non-significant S^2d_i with desirable higher mean and significantly lower b_i than unity was finalized as more than average stable (adaptable to poor environments). Significant S^2d_i was treated as an unpredictable behaviour of genotypes.

Fig 2 showing overall distribution of parents and hybrids according to stability parameters. For fruit yield per plant, 'ISD-006 × GAB-6' (fruit yield: 3320.55 g), 'JDNB-16-1 × GOB-1' (fruit yield: 3152.01 g) and 'ABSR-2 × GAB-6' (fruit yield: 3090.76 g) were the top three stable crosses; 'Ph-9 × Arka Harshita' and 'Ph-6 × GAB-6' were considered as a desirable for unfavourable environments, while 'ISD-006 × GRB-5' (highest fruit yield: 3733.38 g), 'JDNB-16-1 × P. Anupam' and 'ABSR-2 × GOB-1' were appropriate for



Numbering of the parents and their hybrids '( )' for graphical presentation in checkerboard

Testers \ Lines	(1) Arka Komal	(2) Ph-6	(3) Ph-9	(4) PPL	(5) JDNB-16-1	(6) ISD-006	(7) CO2	(8) ABSR-2
(9) GOB-1	(15)	(21)	(27)	(33)	(39)	(45)	(51)	(57)
(10) GAOB-2	(16)	(22)	(28)	(34)	(40)	(46)	(52)	(58)
(11) GAB-6	(17)	(23)	(29)	(35)	(41)	(47)	(53)	(59)
(12) GRB-5	(18)	(24)	(30)	(36)	(42)	(48)	(54)	(60)
(13) Arka Harshita	(19)	(25)	(31)	(37)	(43)	(49)	(55)	(61)
(14) P. Anupam	(20)	(26)	(32)	(38)	(44)	(50)	(56)	(62)

● : Genotypes having non-significant S^2D_i and non-significant b_i value
○ : Genotypes having significant S^2D_i value
+ : Genotypes having non-significant S^2D_i and significant b_i value

Fig 2: Overall distribution of parents and hybrids according to the stability parameters.

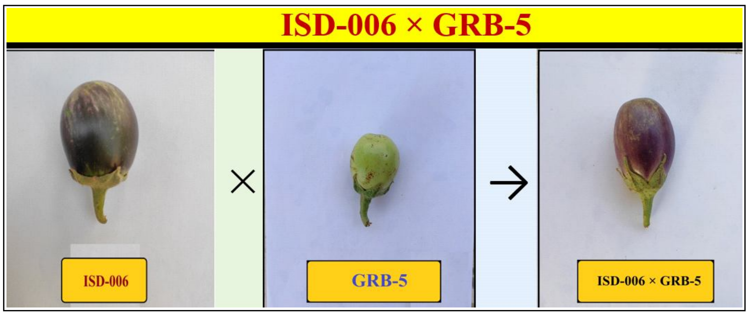


Fig 3: The hybrid ISD-006 × GRB-5 and its parents.

favourable environments. Among these, the hybrid 'ISD-006 × GRB-5' and its parents have shown in Fig 3 due to their superior performance in the experiment.

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. Siva *et al*. (2020) reached a similar type of result.

CONCLUSION

After the precise analysis of heterosis and stability, we conclude that the hybrid 'ISD-006 × GRB-5' and its parents may be directly used in future breeding program. This hybrid showed the highest desirable mean value and noticeable economic heterosis in individuals and pooled over the environments, for fruit yield per plant and the majority of its attributing traits (fruit girth, fruit weight, total soluble solids, chlorophyll content index). It was also desirable in terms of early flowering and early picking. It was average stable for days to opening of first flower, fruit girth, plant height and plant spread; suitable for favourable environment for fruit weight and fruit yield per plant. Also, the desirable hybrids found in this study can create transgressive segregants in brinjal and should be analysed further for getting more knowledge on their genetic structures and gene actions.

Conflict of interest

We don't have any conflict of interest regarding this experiment.

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