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Combining ability and gene action studies for yield and its attributing traits in brinjal (*Solanum melongena* L.)

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Abstract

The results of ANOVA for combining ability revealed that the mean sum of squares for both GCA and SCA were highly significant for all the traits under investigation (excluding days to 50% flowering). This indicates the involvement of both additive and non-additive gene actions in the inheritance of all analyzed traits while, for days to 50% flowering only the GCA mean sum of squares was highly significant which indicates that additive gene action was involved in the inheritance of this trait. The σ^2_{SCA} was higher than σ^2_{GCA} for all traits which earlier recorded for both types of significant gene action denoting the prevalence of non-additive gene action for these traits except days to 50% flowering. The highest GCA effect was observed in AB-08-14 for fruit yield plant^{-1}, fruit diameter and number of marketable fruit plant^{-1}. AB-08-14 × GBL-3, AB-08-14 × Pusa Kranti and JDNB-110 × NBL-15 were the top 3 best specific combiners for fruit yield plant^{-1}. Furthermore, the parents with the best *per se* performance were also observed as the best general combiners indicating a positive coalition between *per se* performance and GCA and the hybrids with high SCA effects do not necessarily involve the parents exhibiting high GCA effects. Which showed the importance of inter-allelic interactions for the inheritance of such traits. SCA which have non-fixable genetic materials were potential parameters for heterosis breeding for brinjal where, commercial exploitation of heterosis is feasible and choice of best hybrid combination based on GCA and SCA effects supplemented with *per se* performance could be more realistic and useful.

Keywords: GCA, SCA, gene action, *per se* performance

Introduction

Brinjal or eggplant is one of the most important vegetables grown worldwide, especially in Asia. The word "Brinjal" is a corruption of the Sanskrit word "*vatin-gan*". It belongs to the family Solanaceae with a chromosome number 2n = 24. According to Vavilov (1928) [16], the center of origin of the brinjal is the Indo-Burma region. It is also considered as one of the most remunerative vegetables (Pramanik *et al.*, 2012) [9]. It is widely grown in both tropical and subtropical regions of the world mainly for its immature fruits as vegetables. It is very popular among people of all social strata and hence, it is referred as the "vegetable of masses" (Patel and Sarnaik, 2003) [7]. Production of brinjal has increased by 50% in the past decade likewise, the demand due to its health benefits. The lack of appropriate hybrids for specific areas and purposes is the major problem in popularizing the hybrids of brinjal. Being a center of origin, brinjal has a huge genetic diversity in India which offers great scope for improvement through heterosis breeding. Which, improves its quality and productivity without sacrificing the consumers' preferences. The selection of parents to obtain good hybrids is an important step for any breeding programme. The selection of parents with GCA and SCA helps the breeder to obtain good hybrids. In the hybridization programme, the nature of gene action controlled by the genetic structure and divergence among populations involved in the hybridization. Therefore, a breeder is expected to know the genetic potential of the parents by estimating their combining ability. A knowledge of general combining ability (GCA) and specific combining ability (SCA) helps in the selection of parents or hybrids and the nature of gene action provides a basis for selecting an effective breeding methodology. The estimation of combining ability effects aids in selecting the desirable parent and crosses for the exploitation of heterosis or to accumulate fixable genes.

In this context, the present investigation was carried out to encapsulate information based on the nature of gene action and combining ability of brinjal genotypes for superior hybrids with best qualities accompanied by high yields for commercial exploitation.

Materials and Methods

The present experiment was carried out at Regional Horticulture Research Station, Navsari, which is situated 12 km away from the "The Dandi", geographically a coastal region of south Gujarat at the latitude of 20°37' N and longitude of 72°54' E with an altitude of 11.89 metres above the mean sea level. The experimental material comprised of 6 parents, 15 cross combinations and 1 standard check (GAOB-2). The genotypes used as parents and their sources are listed in Table 1. In hybridization programme, each of the 6 lines was crossed with each other by following a half-diallel mating design during Rabi 2020-21 to produce 15 hybrids. Randomized block design with three replications was used for the evaluation of genotypes during Rabi 2021-22.

Table 1: The details of parents used in the half-diallel mating design

Parents	Genotypes	Source
P1	AB-08-14	JAU, Junagadh
P2	GBL-3	NAU, Navsari
P3	NBB-1	AAU, Anand
P4	JDNB-110	NBPGR collection
P5	NBL-15	NAU, Navsari
P6	Pusa Kranti	NAU, Navsari

This study evaluates thirteen traits *viz.*, days to 50% flowering, plant height (cm), number of branches plant^{-1}, fruit length (cm), fruit diameter (cm), fruit weight (g), number of fruits plant^{-1}, number of marketable fruits plant^{-1}, fruit yield plant^{-1}(kg), total soluble solids (°Brix), vitamin C (mg 100^{-1}), total phenol content (mg 100^{-1}) and total anthocyanin content (mg 100^{-1}) from randomly selected five tagged plants and average values were computed. Combining ability analysis was performed with the data obtained for parents and hybrids according to Model-I and Method-II respectively proposed by Griffing (1956) [5].

Results and Discussion

The ANOVA of combining ability for various traits is presented in Table 2. It was analyzed that both GCA and SCA variances were significant for all the traits, except for days to 50% flowering. The significance of both GCA and SCA variances for most of the traits suggested that both additive as well as non-additive types of gene actions were involved in the inheritance of these traits and for days to 50% flowering only GCA mean sum of squares were highly significant which suggested the involvement of only additive gene action in inheritance of this trait. The results follow the findings of earlier workers *viz.*, Shafeeq *et al.* (2013) [13], Desai *et al.* (2017) [3], Chaitanya *et al.* (2018) [2], Kachouli *et al.* (2019) [6], Deshmukh *et al.* (2020) [4] and Pramila *et al.* (2020) [10].

Table 2: Analysis of variance for combining ability of various traits in brinjal

Source of Variation	d. f.	Days to 50% Flowering	Plant Height	Number of Branches Plant^{-1}	Fruit Length	Fruit Diameter	Fruit Weight	Number of Fruits Plant^{-1}
GCA	5	41.47**	504.12**	10.11**	3.101**	0.734**	158.370**	60.717**
SCA	15	3.30	136.30**	1.13**	2.194**	0.601**	92.152**	61.016**
Error	40	206.12	10.92	0.32	0.179	0.042	7.894	3.365
σ^2_{GCA}	-	4.54	61.65	1.22	0.365	0.086	18.809	7.168
σ^2_{SCA}	-	-1.84	125.38	0.80	2.014	0.558	84.258	57.651
$\sigma^2_{GCA}/\sigma^2_{SCA}$	-	-2.46	0.49	1.51	0.181	0.154	0.223	0.124

*- Significant at 5% and **- Significant at 1%

Table 2: Analysis of variance for combining ability of various traits in brinjal (conti.)

Source of Variation	d. f.	Number of Marketable Fruits Plant^{-1}	Fruit Yield Plant^{-1}	Total Soluble Solids	Vitamin C	Total Phenol Content	Total Anthocyanin Content
GCA	5	51.393**	0.295**	0.399**	9.197**	21.19**	32.633**
SCA	15	47.385**	0.298**	0.161**	12.286**	38.51**	16.388**
Error	40	2.036	0.020	0.020	0.2372	0.43	0.687
σ^2_{GCA}	-	6.169	0.0344	0.0474	1.210	2.59	3.993
σ^2_{SCA}	-	45.348	0.277	0.140	12.04	38.07	15.700
$\sigma^2_{GCA}/\sigma^2_{SCA}$	-	0.136	0.123	0.336	0.100	0.068	0.2543

*- Significant at 5% and **- Significant at 1%

The mean sum of squares due to GCA and SCA alone may not give us an accurate depiction of gene effects and therefore, the ratio of variances due to GCA and SCA was calculated. In the present experiment, the σ^2_{SCA} was higher than σ^2_{GCA} for all traits under the study except days to 50% flowering and the number of branches plant^{-1} denoting preponderance of non-additive gene action for these traits and it is confirmed by $\sigma^2_{GCA}/\sigma^2_{SCA}$ ratio. Thus, these traits might be governed by dominance, additive x dominance and/or dominance x dominance type of gene action. Similar results are recorded by Akpan *et al.* (2016) [1], Sharma *et al.* (2016) [14], Ramani *et al.* (2017) [12], Patil *et al.* (2019) [8] and Siva *et al.* (2020) [15].

In the present study, significant GCA effects were observed for majority of the traits. The analysis of variance revealed that among parents, the highest GCA effect for fruit diameter, number of marketable fruit plant^{-1} and fruit yield plant^{-1} was observed in P1. This parent also had significant GCA effect for all traits [except plant height, fruit weight and total phenol content where, it showed average general combining ability effect]. The highest GCA effect for fruit weight as well as significant and positive GCA effect for fruit yield plant^{-1}, total soluble solids and vitamin C content reported in P2. P4 reported highest GCA effect for plant height and number of branches plant^{-1} as well as positive and significant GCA effect for fruit weight, fruit yield plant^{-1} and P4 was only parent with significant GCA effect for all fruit quality parameters. P6 had highest GCA effect for fruit length. The GCA effect for highest number of fruit plant^{-1} observed in P5 although this parent reported poor general combiner for all quality parameters as well as other component traits. P3 considered as a poor general combiner as it reported poor and average combiner for all traits except total soluble solids and total phenol content. The traits-wise estimates of general combining ability effects for each parent are presented in Table 3.

Table 3: The general combining ability effects of parents for various traits in brinjal

Parents	DFF	PH	NB	FL	FD	FW	NFP	NMFP	FYP	TSS	VIC	TPC	TAC
P1	-1.708* (G)	1.688 (A)	0.648* (G)	0.299* (G)	0.554* (G)	1.597 (A)	2.311* (G)	2.437* (G)	0.219* (G)	0.113* (G)	1.200* (G)	-0.16 (A)	2.101* (G)
P2	0.542 (A)	4.417* (G)	0.332 (A)	-0.078 (A)	-0.055 (A)	2.889* (G)	-0.573 (A)	-0.78 (A)	0.094* (G)	0.113* (G)	0.695* (G)	1.17* (P)	0.164 (A)
P3	3.750* (P)	1.396 (A)	-0.300 (A)	-0.257 (A)	-0.017 (A)	0.014 (A)	-5.043* (P)	-4.648* (P)	-0.285* (P)	0.175* (G)	0.309 (A)	-1.15* (G)	-3.311* (P)
P4	0.750 (A)	10.083* (G)	1.503* (G)	0.034 (A)	-0.005 (A)	2.014* (G)	-0.143 (A)	0.241 (A)	0.095* (G)	0.150* (G)	0.466* (G)	-2.12* (G)	1.212* (G)
P5	-2.792* (G)	-12.946* (P)	-1.820* (P)	-0.941* (P)	-0.371* (G)	-8.861* (P)	2.387* (G)	1.629* (G)	-0.185* (P)	-0.175* (P)	-0.888* (P)	2.45* (P)	-1.408* (P)
P6	-0.542 (A)	-4.637* (P)	-0.364 (A)	0.943* (G)	-0.106 (A)	2.347* (G)	1.061 (A)	1.121* (G)	0.061 (A)	-0.375* (P)	-1.781* (P)	-0.20 (A)	1.242* (G)

*- Significant at 5% and **- Significant at 1%

DFF	=	Days to 50% Flowering	PH	=	Plant Height (cm)	NB	=	Number of Branches Plant^{-1}
FL	=	Fruit Length (cm)	FD	=	Fruit Diameter (cm)	FW	=	Fruit Weight (g)
NFP	=	Number of Fruits Plant^{-1}	NMFP	=	Number of Marketable Fruits Plant^{-1}	FYP	=	Fruit Yield Plant^{-1} (kg)
TSS	=	Total Soluble Solids (°Brix)	VIC	=	Vitamin C (mg 100^{-1})	TPC	=	Total Phenol Content (mg 100^{-1})
TAC	=	Total Anthocyanin Content (mg 100^{-1})						

Based on GCA effects, all the parents were found good combiners (except P3) for yield attributing characters. However, in general, the parents, which gave the best *per se* performance, was/were also the best general combiners suggesting a positive correlation between these two parameters. This is true with P1, P2 and P6 for fruit yield plant^{-1}, fruit weight and number of fruits plant^{-1} respectively and involvement of these parents provide promising hybrids. This analysis suggested that the selection of parents involved in hybridization could also be considered on *per se* performance, besides GCA effects. The similar results were also observed by Rai and Asati (2011) [11], Shafeeq *et al.* (2013) [13], Sharma *et al.* (2016) [14] and Chaitanya *et al.* (2018) [2].

The information on GCA complemented with SCA and hybrid performance is important for fully exploitation of heterosis. The trait-wise estimates of SCA effects for 15 hybrids are presented in Table 4. Among 15 hybrid combinations, none of the hybrid recorded significant and negative SCA effect for Days to 50% flowering and for fruit yield plant^{-1}, 7 hybrids showed significant and positive SCA effect. With respect to fruit yield plant^{-1}, Top 3 best specific combiner were, P1 × P2, P1 × P6 and P4 × P5. The hybrids exhibiting high SCA effects do not always involve the parents having high GCA effects. These suggest that inter-allelic interactions were important for various traits. The cross with high SCA effects involving at least one general combiner indicates an Additive × Dominance type of gene action. The crosses involving Poor × Poor and Poor × Average general combiner indicate Dominance × Dominance type of gene interaction. The crosses involving one general combining parent could produce desirable transgressive segregants in successive generations. Similar results have been reported by Sharma *et al*., (2016) [14] and Deshmukh *et al*. (2020) [4].

Table 4: Specific combining ability (SCA) effects for different traits in brinjal

Sr. No.	Hybrids	DFF	PH	NB	FL	FD	FW	NFP	NMFP	FYP	TSS	VIC	TPC	TAC
1	P1 × P2	-	9.28**	1.03*	-0.04	1.80**	2.24	11.30*	8.63**	0.87**	-0.17	1.41**	-7.53**	-1.19*
2	P1 × P3	-	-8.79**	0.91*	1.67**	-0.67**	-0.21	6.89*	6.31**	0.42**	-0.01	1.93**	-6.58**	3.94**
3	P1 × P4	-	22.41**	1.53**	-0.06	-0.38**	-2.88	-4.07*	-3.18**	-0.42**	0.15	1.09**	-1.11*	1.70**
4	P1 × P5	-	-5.65**	0.18	-0.41	-0.64**	-7.00**	-4.13*	-2.84**	-0.50**	0.31**	3.37**	1.39**	1.28*
5	P1 × P6	-	2.06	-0.20	1.08**	0.01	11.45**	-3.80*	-2.84**	0.42**	-0.19	1.45**	0.17	-6.00**
6	P2 × P3	-	17.17**	1.06*	-0.89**	-0.63**	-6.17**	-4.16*	-3.65**	-0.51**	1.19**	4.17**	6.80**	4.09**
7	P2 × P4	-	-12.18*	0.01	-1.01**	-0.48**	-6.83**	5.69*	6.34**	0.15	0.28*	2.49**	0.07	-0.88
8	P2 × P5	-	6.14*	0.67	-0.74*	0.07	4.36*	0.49	1.17	0.21*	-0.19	-0.16	-0.93	-0.68
9	P2 × P6	-	0.94	0.21	-1.32**	0.80**	9.82**	-6.21*	-4.92**	-0.10	0.11	1.44**	.6.15**	3.89**
10	P3 × P4	-	-9.36**	0.72	-0.32	-0.39**	1.36	11.43*	9.47**	0.83**	-0.14	3.33**	8.04**	-5.23**
11	P3 × P5	-	5.83*	-0.94*	-0.34	1.02**	12.91**	-5.02*	-4.28**	0.10	-0.31**	-0.62	-8.55**	-1.87**
12	P3 × P6	-	4.02	-0.98*	0.99**	-0.01	7.36**	-7.41*	-6.47**	-0.32*	-0.05	-3.25**	2.13**	0.74
13	P4 × P5	-	14.48**	-0.25	2.94**	0.21	14.91**	3.01*	4.26*	0.76**	0.13	3.32**	-8.72**	1.37*
14	P4 × P6	-	-0.39	-1.37**	1.90**	0.82**	8.70**	-5.68*	-4.65**	-0.04	-0.06	-3.88**	-6.07**	7.29*

15	P5 × P6	-	-14.29**	0.19	-1.49**	-0.76**	-10.75**	16.14*	13.98**	0.38**	0.06	-3.49**	0.93	4.71**
	S. E. (sij)±	-	2.92	0.50	0.37	0.18	2.49	1.62	1.26	0.12	0.12	0.43	0.58	0.73

*- Significant at 5% and **- Significant at 1%

DFF	=	Days to 50% Flowering	PH	=	Plant Height (cm)	NB	=	Number of Branches Plant^{-1}
FL	=	Fruit Length (cm)	FD	=	Fruit Diameter (cm)	FW	=	Fruit Weight (g)
NFP	=	Number of Fruits Plant^{-1}	NMFP	=	Number of Marketable Fruits Plant^{-1}	FYP	=	Fruit Yield Plant^{-1} (kg)
TSS	=	Total Soluble Solids (°Brix)	VIC	=	Vitamin C (mg 100^{-1})	TPC	=	Total Phenol Content (mg 100^{-1})
TAC	=	Total Anthocyanin Content (mg 100^{-1})						

Based on combining ability analysis, although both GCA and SCA effects are significant, the majority of non-additive genetic variance indicated the presence of heterozygosity in the population. As this kind of genetic variation cannot be fixed, heterosis breeding is an effective tool for crop improvement and breeding method like, diallel selective mating and recurrent selection can be used in advance generation. Genotypes having high GCA effects for many yield attributing characters *viz*., P1, P2 and P4 can also be recommended for use as one of the parents to develop hybrids with high yield and superior quality as well as in varietal improvement programmes.

Conclusion
It is evident from the above results that although both GCA and SCA effects are significant, the majority of non-additive genetic variance suggested the existence of heterozygosity in the population. As this kind of genetic variation cannot be fixed, heterosis breeding is an effective approach for crop improvement and breeding methods like, diallel selective mating and recurrent selection can also be used in advanced generations.

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