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Combining ability estimates for yield and quality traits in line × tester crosses of bitter gourd (*Momordica charantia* L.)

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Abstract
Thirteen parental lines and 30 F_1 hybrids of bitter gourd obtained from Line × Tester mating design were studied to investigate the extent of combining ability for yield and quality characters. These parents along with their hybrids were evaluated in a randomized block design (RBD) with three replications. The analysis of variance for combining ability revealed that the mean sum of squares due to lines and testers were highly significant for almost all the characters under study except for vine length, number of primary branches per plant, fruit width and total soluble solids (TSS) content for which testers showed no significant differences. The estimated component of variance of specific combining ability (sca) was higher than general combining ability (GCA) for all the characters except fruit width indicating the predominance of non-additive gene actions for most of the characters under study. The lines IC-085612, Jaunpuri Green, IC-085611 and Katehi were found to be good general combiners for fruit yield as well as for quality parameters. These lines can be exploited in future breeding programme for improvement in bitter gourd. Among 30 cross combinations, the crosses IC-085611 × Meghna, OBGCS-1 × Katheri and Jaunpuri Green × Meghna exhibited high sca effects for various yield and its attributing traits. These crosses could be further exploited for the production of F_1 hybrids.

Keywords: Combining ability, general combining ability, specific combining ability, variance, F_1 hybrids

Introduction

Bitter gourd or balsam pear (*Momordica charantia* L.) having the chromosome number of 2n=2x=22, is an important vegetable crop belongs to the family cucurbitaceae. The crop is of Asiatic origin and the probable place of origin is either China or India (Behera 2005) [2]. The importance of bitter gourd has been recognized due to its nutritive value and medicinal properties. It ranks first among cucurbits due to high value of minerals and vitamins. In India, bitter gourd is grown throughout the country as summer and rainy season vegetable crop. Due to cross pollinating and monoecious nature of the crop, bitter gourd shows a lot of variability in yield and yield contributing components. However, it does not suffer from inbreeding depression and it seems that the population structure is similar to that of in breeders than out breeders (Allard, 1960) [1]. The concept of combining ability for the evaluation of parents in a crossing programme is of immense importance. For a successful breeding programme, the first and most important step is the selection of suitable parents for hybridization aiming to develop a superior pure line or hybrid crop varieties having high yield and quality. Combining ability studies aims to identify inbred lines with good GCA and sca effects for different economic characters. On the basis of high gca (General Combining Ability) estimation, good combiner parental inbred lines can be selected which are involved in hybrid combinations to detect the best hybrids, through the comparison among sca values. A high sca values of particular combination means that the parents of this hybrid can produce a superior hybrid. Combining ability analysis is a useful approach for gaining knowledge about the genetic worth of parents and crosses for further exploitation in breeding programme. In addition, it also provides information about gene effects involved in the inheritance of various characters, which is essential for deciding suitable breeding strategy. Among the various methods available for the analysis of combining ability, the line × tester analysis given by Kempthorne (1957) [5] has been most widely used method for screening of germplasm to identify suitable donor parents

and their crosses for breeding programmes in many crops including bitter gourd. Thus, the present investigation was carried out to identify the best combiner inbred lines and their crosses on the basis of general and specific combining ability effects for yield and its attributing traits in bitter gourd.

Material and Methods
The study was designed to work out the extent combining ability in bitter gourd using Line x Tester analysis at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during the year 2017-2018. A total of thirteen parents comprised of ten lines *i.e.,* Katehi, IC-085612, BGCV-2, OBGCS-4, OBGCS-2, OBGCS-3, Jaunpuri Green, Shaktigopal Local, OBGCS-1, IC-085611, and three testers, namely Katheri, Preethi and Meghna were chosen from germplasm maintained by continuous selfing at Department of Horticulture, Institute of Agricultural Sciences, BHU. These parents were crossed in a Line × Tester mating design during the *kharif* season of 2017. Thus a total number of thirty crosses with their corresponding parents were evaluated in *kharif* season of 2018 for various quantitative and qualitative traits. The trial was conducted in randomized block design (RBD) with 3 replications. Each plant was grown at $1.5 × 0.6$ m^2 spacing. Observations on various yield and quality traits *viz.,* vine length, number of primary branch per plant, fruit length, fruit width, average fruit weight, number of fruits per plant, number of seeds per fruit, fruits yield per plant, total soluble solids and ascorbic acid content were recorded on five randomly selected single plants in each replication. The average values were utilized for statistical analysis. Statistical analysis *viz.*, analysis of variance; and estimation of general and specific combining ability were conducted as per the procedures outlined by Panse and Sukhatme (1967) [11] and Kempthrone (1957) [5] respectively.

Result and Discussion
Analysis of variance (ANOVA) for combining ability
The analysis of variance for combining ability for all characters showed that (Table 1) mean squares due to lines were found to be significantly different for all the traits under study. For testers, there were no differences among genotypes for vine length, number of primary branches per plant, fruit width and total soluble solids (TSS) content. Similarly the interaction between lines and testers were stated as significant for all traits except fruit width. These estimates indicate the presence of an appreciable amount of variability in lines, testers and lines *vs.* testers. The combining ability analysis also gives an indication of the variance due to sca and gca, which represents a relative measure of non-additive and additive gene actions respectively. The estimates of variance component due to specific combining ability were found to be higher than those of general combining ability for all the traits studied except fruit width. This indicated the predominance of non-additive type of gene action in the inheritance of the traits and hence heterosis breeding could be better exploited for improvement of these traits. However, pure line selection is suggested for the improvement of the trait fruit width as it was controlled by additive gene action. These results are in corroborative with the findings of Khattra *et al.* (2000) [6]; and Jadhav *et al.* (2010) [4] who reported non-additive gene action for yield related characters in bitter gourd. However, Matoria and Khandelwal (1999) [9] found that both non-additive and additive gene action were involved in the expression of yield related characters in bitter gourd.

Table 1: Analysis of variance for combining ability for various yield and quality traits in bitter gourd

Source of Variations	d.f.	Mean Sum of Squares									
		Vine length (m)	Number of primary branches per plant	Fruit length (cm)	Fruit width (cm)	Number of fruits per plant	Average fruit weight (g)	Number of seeds per fruit	Fruit yield (q/ha)	Total soluble solid (°Brix)	Ascorbic acid (mg/100 g of fruit)
Replicates	2	0.10	1.20	1.69	0.16	0.94	0.96	0.14	116.51	0.40	0.10
Line Effect	9	1.68 **	5.52 **	24.00 *	1.18 **	34.66 **	356.24 **	28.47 **	6660.59 *	0.93 **	1157.60 **
Tester Effect	2	0.62	4.06	15.49 **	0.15	20.78 **	118.16 **	51.21 **	3459.93 **	0.76	96.18 **
Line × Tester Eff.	18	1.25 **	6.19 **	6.95 **	0.10	18.55 **	72.75 **	28.86 **	2295.97 **	2.00 **	1345.65 **
Error	58	0.39	1.29	1.20	0.14	0.76	1.09	1.15	51.82	0.11	4.98
Total	89	0.690	2.767	5.000	0.238	8.242	54.127	10.620	1252.033	0.599	394.623
σ^2gca		0.04	0.18	0.96	0.03	1.38	12.11	1.98	256.84	0.04	31.92
σ^2sca		0.29	1.66	1.95	0.02	5.91	23.92	9.24	748.05	0.63	447.06
σ^2gca/σ^2sca		0.14	0.11	0.49	1.5	0.23	0.51	0.21	0.34	0.063	0.07

*Significant at p=0.05, **Significant at p=0.01

Table 2: Estimates of general combining ability effects of parents for various yield and quality traits in bitter gourd

Genotypes	Vine length (m)	Number of primary branches per plant	Fruit length (cm)	Fruit width (cm)	Number of fruits per plant	Average fruit weight (g)	Number of seeds per fruit	Fruit yield (q/ha)	Total soluble solid (°Brix)	Ascorbic acid (mg/100g of fruit)
Lines										
Katehi	0.78 **	0.22	-0.28	-0.12	1.02 **	2.85 **	0.29	12.90 **	-0.45 **	-15.12 **
IC-085612	0.37	0.26	0.99 **	0.59 **	2.43 **	3.91 **	3.00 **	25.82 **	0.05	12.79 **
BGCV-2	-0.20	-1.41 **	1.95 **	0.31 *	-0.30	2.90 **	-3.87 **	3.27	-0.27 *	10.27 **
OBGCS-4	-0.43 *	-0.25	1.80 **	0.27 *	0.27	4.68 **	0.19	10.95 **	0.12	-13.42 **
OBGCS-2	-0.03	-1.14 **	-0.31	-0.15	-2.12 **	-4.73 **	0.64	-26.41 **	0.42 **	-5.36 **
OBGCS-3	-0.32	-0.11	-1.52 **	-0.48 **	-2.57 **	-9.73 **	1.22 **	-39.02 **	-0.14	8.58 **
Jaunpuri Green	-0.37	1.21 **	1.87 **	0.15	2.72 **	6.54 **	0.51	35.42 **	0.33 **	-11.31 **
Shaktigopal Local	-0.49 *	0.65	-2.74 **	-0.61 **	-2.79 **	-10.98 **	-1.24 **	-43.19 **	0.45 **	2.42 **
OBGCS-1	0.35	0.27	-0.21	-0.01	0.25	-0.14	0.08	1.45	-0.32 **	-3.95 **
IC-085611	0.34	0.30	-1.55 **	0.05	1.09 **	4.70 **	-0.82 *	18.83 **	-0.19	15.10 **
CD (95%)	0.41	0.73	0.70	0.25	0.60	0.67	0.72	4.80	0.21	1.41

Testers										
Katheri	0.16	-0.10	-0.83 **	-0.08	0.21	-0.82 **	0.99 **	-0.67	-0.18 **	2.06 **
Preethi	-0.11	-0.31	0.36	0.03	-0.92 **	-1.44 **	-1.48 **	-10.39 **	0.13 *	-0.87 *
Meghna	-0.05	0.41 *	0.47 *	0.05	0.71 **	2.26 **	0.49 *	11.06 **	0.04	-1.19 **
CD (95%)	0.22	0.40	0.39	0.14	0.33	0.37	0.39	2.63	0.12	0.77

*Significant at p=0.05, **Significant at p=0.01

General combining ability effects

The combining ability analysis helps in selection of suitable parents for developing desirable hybrids by estimating general combining ability (gca) and specific combining ability (sca) in the crosses. General combining ability (gca) represents the average performance of a line in a series of crosses in which that line is a common parent, and specific combining ability (sca) represents the better performance of a cross combination which is expected on the basis of gca of the two parents involved in that cross.

The estimates of general combining ability of thirteen parents for ten characters are presented in Table 2. The gca effects varied from one parent to another giving negative or positive value and were found to be highly significant among the genotypes. The parental line Katehi exhibited desirable significant positive gca for vine length, means that, this genotype could be considered as good combiner for this trait. Similarly, the line Jaunpuri Green and tester Meghna appeared as very good combiners for number of primary branches per plant as both of them expressed highly significant positive gca effects for the above mentioned trait. Yadav et al. (2008) [19]; Kumara et al. (2011) [7]; Patil et al. (2012) [12]; and Singh et al. (2013) [15] agreed with the results of present study. With respect to fruit length, the parental line BGCV-2, Jaunpuri Green and OBGCS-4 were found to be good combiners while the line IC-085612 followed by BGCV-2 and OBGCS-4 showed good combining ability for fruit width since these parents showed significant gca effects in a suitable positive direction for both the traits. Parent Jaunpuri Green had the highest significant positive gca effects for individual fruit weight followed by IC-085611 and OBGCS-4.

Thus, these parents were considered as the best general combiner to use in crosses for the improvement of individual fruit weight as indicated by their significant and higher gca effects. On the other hand BGCV-2 showed highest negative significant gca effect for number of seeds per fruit followed by Shaktigopal Local and Preethi, thus considered as good general combiner. Similar results for number of seeds per fruit were also reported by Devadas and Ramadas (1995) [3]; Khattra et al. (2000) [6]; and Kumara et al. (2011) [7]. Among the parents, four lines i.e. Jaunpuri Green, IC-085612, IC-085611, Katehi and one tester Meghna had significant and positive gca effects for fruit yield as well as for number of fruits per plant. These parents regarded as good general combiner for the above traits. Significant gca effects for fruit yield per hectare was also reported by Thangamani et al. (2011) [18]; Kumar et al. (2016) [8]; and Sundharaiya and Venkatesan (2016) [17] in bitter gourd.

The line Shaktigopal Local performed as the best general combiner for higher TSS content followed by OBGCS-2, Jaunpuri Green and tester Preethi, since these parents had the higher and significant positive gca effects.

For ascorbic acid content, the top three best performing genotypes exhibiting highest and significant gca effects was IC-085611 followed by IC-085612 and BGCV-2. These results were in conformity to the report of Mallikarjunarao et al. (2018) [10] in bitter gourd.

Specific combining ability effects

Analysis of specific combining ability is a useful parameter for judging the performance of specific cross combinations for exploiting it through heterosis breeding programme. The good specific cross combinations are selected based on their sca effects. High sca effects of a cross combination arise as a result of crosses involving high as well as low combiners. Estimation of specific combining ability effects calculated for each of the hybrids is given in table 3. Analysis of sca effects for the character vine length revealed that out of 30 crosses, only three cross combinations exhibited significant positive sca values. The crosses namely, IC-085611 × Meghna, OBGCS-3 × Preethi and IC-085612 × Katheri showed high positive sca values, thus presumed as good specific combiners for this trait. Four cross combinations out of 30 crosses were observed to have significantly higher positive sca effects for number of primary branches per plant and these were IC-085611 × Meghna, OBGCS-1 × Katheri, Katehi × Meghna and IC-085612 × Katheri. These results were in conformity to the report of Patil et al. (2012) [12]; and Singh et al. (2013) [15] in bitter gourd. Regarding the trait fruit length, only four crosses i.e., IC-085611 × Meghna, IC-085612 × Meghna, Jaunpuri Green × Meghna and Jaunpuri Green × Preethi exhibited maximum and significant sca effects thus appeared as best specific combiners for the trait. However, none of the cross combinations recorded significant sca effects for fruit width. Among thirty cross combinations about twenty one F1s exhibit significant sca values for average fruit weight, of which eleven had significant positive values which are considered to be desirable for the trait. The highest sca effect for average fruit weight was observed for the cross Shaktigopal Local × Preethi followed by OBGCS-1 × Katheri and Jaunpuri Green × Meghna. The results reported by Singh and Joshi (1980) [14]; Singh et al. (2013) [15]; and Sundharaiya and Venkatesan (2016) [17] were also in accordance with these findings. For number of seeds per fruit, the significant negative desirable SCA effects were manifested by nine hybrids. Out of them, the top three hybrids exhibiting highest SCA values for this trait were IC-085612 × Preethi, Katehi × Meghna and BGCV-2 × Meghna. Similar results for number of seeds per fruit were also reported by Devadas and Ramadas (1995) [3]. Among 30 crosses, eleven cross combinations were reported significant sca effect in positive direction for fruit yield per plant, of which the crosses OBGCS-1 × Katheri, IC-085611 × Meghna and BGCV-2 × Katheri were found to be the most promising combinations for the trait. These crosses also had significant desirable sca effects for number of fruits per plant, out of total eight crosses which were reported to have good specific combining ability for the same. The significance of sca registered for number of fruits and yield of fruits per plant in the cross combinations OBGCS-1 × Katheri, IC-085611 × Meghna and BGCV-2 × Katheri with high sca values could be well utilised in heterosis breeding as reported by Sirohi and Choudhury (1977) [13] and Sundaram (2006) [7] in bitter gourd. For quality parameters like total soluble solids (TSS) content and ascorbic acid content, seven and eleven crosses out of 30 cross combinations displayed significantly positive sca effects, respectively. The top three

best specific combiners exhibiting highest SCA values for TSS content were Jaunpuri Green × Preethi, OBGCS-1 × Meghna and OBGCS-4 × Katheri whereas, in case of ascorbic acid content the crosses Shaktigopal Local × Preethi, Jaunpuri Green × Meghna and IC-085612 × Katheri showed good specific combining ability having the significant positive sca effects. The present finding corroborated the earlier work of Mallikarjunarao et al. (2018) [10] in bitter gourd.

From the above studies, it can be concluded that desirable parents having the good combining ability could be used as donor to get high yield and the selective cross combinations which were identified as better combiners for yield and its contributing traits as they possess high sca values, may further be exploited in future breeding programme for improvement in bitter gourd. In terms of best general combiners for most of the traits studied including yield, the lines IC-085612, Jaunpuri Green, IC-085611 and Katehi could be exploited beneficially in future bitter gourd breeding programmes by adopting appropriate breeding procedures. The crosses, IC-085611 × Meghna, OBGCS-1 × Katheri and Jaunpuri Green × Meghna could be exploited for the production of F_1 hybrids and used in recombination breeding in order to evolve high yielding varieties suitable for bitter gourd.

Table 3: Estimates of specific combining ability effects of crosses for various yield and quality traits in bitter gourd

Crosses	Vine length (m)	Number of primary branches per plant	Fruit length (cm)	Fruit width (cm)	Number of fruits per plant
Katehi × Katheri	-0.29	-1.89 **	-0.46	-0.19	-2.30 **
Katehi × Preethi	-0.31	0.40	0.55	-0.15	0.20
Katehi × Meghna	0.61	1.49 *	-0.09	0.33	2.11 **
IC-085612 × Katheri	0.82 *	1.36 *	0.87	-0.03	2.02 **
IC-085612 × Preethi	-0.87 *	-0.62	-2.47 **	0.13	-2.12 **
IC-085612 × Meghna	0.04	-0.75	1.61 *	-0.10	0.09
BGCV-2 × Katheri	0.53	0.38	0.97	0.26	3.15 **
BGCV-2 × Preethi	-0.46	0.41	0.62	0.05	-0.95
BGCV-2 × Meghna	-0.07	-0.79	-1.59 *	-0.31	-2.21 **
OBGCS-4 × Katheri	0.20	0.58	-0.67	0.13	-1.11 *
OBGCS-4 × Preethi	0.20	-0.48	-0.03	-0.10	-0.02
OBGCS-4 × Meghna	-0.41	-0.10	0.70	-0.02	1.13 *
OBGCS-2 × Katheri	0.21	0.33	1.11	-0.05	1.08 *
OBGCS-2 × Preethi	-0.23	0.77	-0.92	0.17	0.24
OBGCS-2 × Meghna	0.03	-1.10	-0.19	-0.12	-1.32 *
OBGCS-3 × Katheri	-0.34	-0.16	0.68	-0.11	-0.78
OBGCS-3 × Preethi	0.89 *	0.24	1.16	-0.11	0.48
OBGCS-3 × Meghna	-0.54	-0.08	-1.85 **	0.22	0.29
Jaunpuri Green × Katheri	-0.61	-1.97 **	-2.76 **	0.02	-3.63 **
Jaunpuri Green × Preethi	0.60	0.77	1.30 *	-0.08	3.10 **
Jaunpuri Green × Meghna	0.00	1.21	1.46 *	0.06	0.54
Shaktigopal Local × Katheri	0.44	0.26	0.67	0.13	-0.59
Shaktigopal Local × Preethi	-0.18	-0.30	0.81	-0.06	0.67
Shaktigopal Local × Meghna	-0.26	0.04	-1.48 *	-0.07	-0.08
OBGCS-1 × Katheri	0.03	1.84 **	-0.03	0.02	3.60 **
OBGCS-1 × Preethi	0.41	0.54	0.28	0.07	0.40
OBGCS-1 × Meghna	-0.44	-2.37 **	-0.26	-0.09	-3.99 **
IC-085611 × Katheri	-0.99 **	-0.73	-0.37	-0.17	-1.43 **
IC-085611 × Preethi	-0.05	-1.72 **	-1.32 *	0.08	-2.00 **
IC-085611 × Meghna	1.04 **	2.45 **	1.68 **	0.10	3.44 **
CD (95%)	0.71	1.27	1.22	0.44	1.04

*Significant at p=0.05, **Significant at p=0.01

Crosses	Average fruit weight (g)	Number of seeds per fruit	Fruit yield (q/ha)	Total soluble solid (°Brix)	Ascorbic acid (mg/100g of fruit)
Katehi × Katheri	-1.98 **	-1.65 **	-21.49 **	-0.13	8.47 **
Katehi × Preethi	1.72 **	4.76 **	5.71	0.19	-5.52 **
Katehi × Meghna	0.25	-3.11 **	15.78 **	-0.05	-2.95 *
IC-085612 × Katheri	-0.35	0.71	13.65 **	-0.03	26.87 **
IC-085612 × Preethi	-2.91 **	-5.79 **	-22.51 **	0.26	-16.97 **
IC-085612 × Meghna	3.26 **	5.08 **	8.86 *	-0.22	-9.90 **
BGCV-2 × Katheri	4.84 **	5.11 **	35.22 **	-0.61 **	-10.37 **
BGCV-2 × Preethi	-4.32 **	-2.25 **	-15.79 **	0.14	17.55 **
BGCV-2 × Meghna	-0.52	-2.85 **	-19.43 **	0.47 *	-7.18 **
OBGCS-4 × Katheri	-1.97 **	-0.62	-12.44 **	0.90 **	20.68 **
OBGCS-4 × Preethi	2.40 **	0.99	5.13	-0.11	-16.66 **
OBGCS-4 × Meghna	-0.43	-0.38	7.32	-0.79 **	-4.02 **
OBGCS-2 × Katheri	1.34 *	1.00	10.18 *	-0.60 **	22.11 **
OBGCS-2 × Preethi	-2.16 **	-0.70	-1.15	0.02	-8.33 **
OBGCS-2 × Meghna	0.82	-0.30	-9.04 *	0.58 **	-13.78 **
OBGCS-3 × Katheri	-1.10	-1.62 *	-6.64	-0.11	-19.84 **
OBGCS-3 × Preethi	-1.07	-0.18	2.71	0.08	14.02 **

OBGCS-3 × Meghna	2.17 **	1.79 **	3.93	0.03	5.81 **
Jaunpuri Green × Katheri	-4.95 **	-0.34	-39.91 **	-0.11	-13.19 **
Jaunpuri Green × Preethi	-0.50	-1.36 *	20.70 **	1.51 **	-17.00**
Jaunpuri Green × Meghna	5.45 **	1.70 **	19.21 **	-1.40 **	30.19**
Shaktigopal Local × Katheri	-1.73 **	0.42	-6.38	0.90 **	-24.57 **
Shaktigopal Local × Preethi	6.96 **	2.36 **	19.68 **	-0.74 **	37.08 **
Shaktigopal Local × Meghna	-5.22 **	-2.78 **	-13.30 **	-0.15	-12.51**
OBGCS-1 × Katheri	6.87 **	-2.40 **	42.18 **	-0.63 **	6.54 **
OBGCS-1 × Preethi	3.70 **	2.27 **	9.98 *	-0.74**	-0.51
OBGCS-1 × Meghna	-10.56 **	0.14	-52.15 **	1.38 **	-6.02 **
IC-085611 × Katheri	-0.98	-0.60	-14.37 **	0.44 *	-16.69**
IC-085611 × Preethi	-3.82 **	-0.10	-24.46 **	-0.60**	-3.65 **
IC-085611 × Meghna	4.79 **	0.70	38.83 **	0.16	20.35**
CD (95%)	1.15	1.24	8.32	0.37	2.44

*Significant at p=0.05, **Significant at p=0.01

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