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Combining ability studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)

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Abstract
Line x tester analysis was conducted to estimate combining ability involving 12 lines and two testers. Their 24 cross-combinations were evaluated in a Randomized Complete Block Design with three replications at the Experimental Farm, Department of Vegetable Science and Floriculture, CSKHPKV, Palampur (H.P.) during summer-rainy season, 2018. Non-additive gene action was observed for first fruit producing node, ridges per fruit, mucilage and fruit yield per plant. On the basis of GCA effects, Parbhani Kranti was found to be a good general combiner for days to first picking, first fruit producing node, fruit length, average fruit weight and fruit yield per plant. VRO-4 and IC-169468 were good general combiners for earliness and fruit yield per plant. The most promising hybrids showing significantly positive sca effects for fruit yield were Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and VRO-4 x Hisar Unnat which could be utilized in further breeding programme.

Keywords: Combining ability, GCA variance, SCA variance, Line × tester.

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] is an important vegetable crop grown throughout the country both as summer as well as rainy season crop. It is believed to have Ethiopian origin and commercially cultivated in West Africa, India, South-East Asia, Southern United States, Brazil, Turkey and Northern Australia. It is also a popular home garden vegetable in many other countries.

Green tender fruits of okra are consumed after cooking. Sometimes it is also available in dehydrated and canned form. It is a good source of nutrients and minerals as 100 g edible portion contains 1.9 g protein, 0.2 g fat, 0.7 g minerals, 0.4 g carbohydrates, 66 mg calcium, 43 mg magnesium, 1.5 mg iron, 6.9 mg oxalic acid, 88 I.U. vitamin A, 63 I.U. vitamin B, 13 mg vitamin C, 0.07 mg thiamine, 0.1 mg riboflavin and 0.6 mg nicotinic acid (Babel and Yadav 1971 [3] and Rekhi 1976 [21]). Mature fruits and stems are used in paper industry, root and stems are used for cleaning the cane juices (Singh 1989) [26]. Apart from its commercial uses, it is said to be very useful against genito-urinary disorders, spermatorrhoea and chronic dysentery (Krishnamurthy 1994) [11].

Okra is grown worldwide in an area of 24,02,039 hectares with production of 96,41,284 metric tons and productivity 4.01 tonnes/ha (FAO Statistics, 2017) [6]. India ranks first in the world with an annual production of 60,95,000 metric tons produced from 5,09,000 hectares area, the average productivity being 11.97 tonnes/ha (Anonymous 2018) [2]. It also has a huge potential to earn foreign exchange and accounts for 60% export of fresh vegetables excluding potato, onion and garlic. The major export destinations are Middle East, United Kingdom, Western Europe and United States of America.

Okra is an often cross-pollinated crop as the natural crossing occurs up to a range of 4-19% (Kumar *et al.*, 2010) [14]. Emasculation and pollination is easy due to large flower and monoadelphous stamens.

Since, yield is the main consideration in heterosis breeding; it is of considerable importance to study the pattern of inheritance of this character as well as various other related components. Combining ability analysis highlights potential parents in the hybridization programme as well as simultaneously screens the crosses. Knowledge of combining ability is important in identifying best general combiners among genotypes and specific combiners among crosses

(Sprague and Tatum 1942) [28]. Therefore, current study was taken up to highlight the potential parents and cross-combinations on the basis of combining ability (GCA & SCA) in okra.

Materials and Methods

The present investigation was carried out during summer rainy season, 2017-18 at the Experimental Farm, Department of Vegetable Science and Floriculture, CSKHPKV, Palampur (H.P.) which is situated at 32°6' N latitude, 76°3' E longitude, having elevation of 1290.80 m above mean sea level. Genotypes used were grown in a crossing block during summer rainy season of 2017. Crosses were attempted in line x tester fashion involving two parents as male and 12 parents as females (Table 1). Seeds were harvested combination wise and sown in Randomized Complete Block Design with three replications in summer rainy season of 2018.

Table 1: Parents and their crosses included in line x tester analysis

S. No.	Lines	S. No.	Lines
1.	P-20	9.	P-23
2.	VRO-4	10.	Japan Red
3.	Parbhani Kranti	11.	Japan 5 Ridged
4.	P-8	12.	Japan Round
5.	Tulsi-1		
6.	SKBS-11	**Testers**	
7.	VRO-6	1.	9801
8.	IC-169468	2.	Hisar Unnat
Crosses			
1.	P-20 x 9801	13.	VRO-6 x 9801
2.	P-20 x Hisar Unnat	14.	VRO-6 x Hisar Unnat
3.	VRO-4 x 9801	15.	IC-169468 x 9801
4.	VRO-4 x Hisar Unnat	16.	IC-169468 x Hisar Unnat
5.	Parbhani Kranti x 9801	17.	P-23 x 9801
6.	Parbhani Kranti x Hisar Unnat	18.	P-23 x Hisar Unnat
7.	P-8 x 9801	19.	Japan Red x 9801
8.	P-8 x Hisar Unnat	20.	Japan Red x Hisar Unnat
9.	Tulsi-1 x 9801	21.	Japan 5 Ridged x 9801
10.	Tulsi-1 x Hisar Unnat	22.	Japan 5 Ridged x Hisar Unnat
11.	SKBS-11 x 9801	23.	Japan Round x 9801
12.	SKBS-11 x Hisar Unnat	24.	Japan Round x Hisar Unnat

Single rows were raised with row to row and plant to plant distances maintained at 45 cm x 15 cm, respectively. Recommended package of practices were followed to raise a healthy crop**.**

Data were recorded for yield and related horticultural traits in okra *viz.*, days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, plant height, harvest duration, fruits per plant, fruit yield per plant, ridges per fruit, dry matter and mucilage. Data of ten plants of each genotype and its crosses were averaged replication wise and mean data was used for statistical analysis. The analysis of variance (ANOVA) for RBD was estimated crosswise as suggested by Panse and Sukhtame (1989) [18] and ANOVA for line x tester analysis was done according to Kempthorne (1957) [9].

Results and Discussion

The analysis of combining ability is one of the potential tools used for identification of prospective parents to develop commercial F_1 hybrids (Griffing 1956) [8]. The analysis of variance for line x tester design showed significant differences among parents for all the traits (Table 2) except fruit diameter and average fruit weight suggesting the presence of substantial amount of genetic variability for exploitation through recombinant breeding. The degree of dominance revealed overdominance for first fruit producing node, ridges per fruit, mucilage and fruit yield per plant indicating the role of non-additive gene action in their inheritance. The results are in conformity with the findings of Singh and Sanwal (2010) [24], Kumar and Pathania (2011) [12] and More *et al*. (2017) [16] for first fruit producing node; Satish *et al*. (2017) [22] for harvest duration; Singh *et al*. (2006) [25], Singh and Sanwal (2010) [24], Kumar and Pathania (2011) [12], Singh *et al*. (2012) [23], Solankey *et al*. (2012) [27], Adiger *et al*. (2013) [1], Lyngdoh *et al*. (2017) [15] and More *et al*. (2017) [16] for fruit yield per plant and Solankey *et al*. (2012) [27] and Lyngdoh *et al*. (2017) [15] for ridges per fruit. Complete dominance was observed for harvest duration while remaining traits showed partial dominance.

General combining ability effects

Line VRO-6 showed highest GCA effects for nodes per plant, internodal length and mucilage. It was observed that parents Parbhani Kranti for fruit length and fruit yield per plant, IC-169468 for first fruit producing node and harvest duration, P-23 for days to first picking and plant height P-8 for average fruit weight, Japan red for ridges per fruit, Japan Round for days to 50 per cent flowering and Japan Round for dry matter showed the highest general combining ability effects (Table 3). VRO-4, Parbhani Kranti and IC-169468 were found to be good general combiners for earliness and fruit yield per plant. Among testers, 9801 was good general combiner for days to 50 per cent flowering, days to first picking, internodal length, fruit length fruit diameter and plant height while Hisar Unnat for nodes per plant, harvest duration, fruits per plant, fruit yield per plant and mucilage. Similar results in okra were reported by Bhatt *et al*. (2015) [4], Kumar and Reddy (2016) [13], Verma *et al*. 2016 [31], Vani *et al*. (2017) [30] and Eswaran and Anbanandan (2018) [5]. An overall study of gca revealed that none of parent was good combiner for all characters under investigation (Patil *et al*. 2016 [19], Wakode *et al*. 2016 [32], Paul *et al*. 2017 [20] and Gavint *et al*. 2018) [7], which is due to the different genetic composition of the parents included in the study.

Table 2: Analysis of variance for parents and hybrids (line x tester) for fruit yield and horticultural traits in okra

Source of variation	Replication	Parent	Line	Tester	Line vs Tester	Hybrid	Parent vs Hybrid	Error	Genetic components		
Traits df	2	13	11	1	1	23	1	74	σ^2A	σ^2D	$(D/A)^{1/2}$
Days to 50 per cent flowering	0.10	139.37*	147.56*	48.22*	140.49*	23.77*	263.86*	1.86	4.70	1.75	0.61
Days to first picking	0.59	67.89*	75.06*	0.67	56.19*	15.65*	194.57*	2.81	2.94	1.19	0.64
First fruit producing node	0.04	3.18*	3.61*	1.50*	0.16	2.57*	1.01	0.26	0.19	0.35	1.35
Nodes per plant	2.12	50.23*	21.72*	2.94	411.19*	16.90*	95.69*	8.51	4.03	-	-
Internodal length (cm)	0.98	16.23*	14.94*	38.15*	8.53*	12.63*	0.09	1.62	3.58	0.78	0.47
Fruit length (cm)	0.15	3.01*	3.19*	3.75*	0.39	1.17*	0.00	0.50	0.33	-	-

Fruit diameter (cm)	0.03	0.19	0.17	0.33	0.21	0.06	0.41	0.14	0.03	-	-
Average fruit weight (g)	2.90	8.28	9.06	0.03	7.90	12.63*	25.80*	5.25	1.15	0.90	0.88
Plant height (cm)	23.68	7104.46*	3864.61*	31363.74*	18483.44*	4251.65*	10680.66*	52.09	751.62	23.26	0.28
Harvest duration (days)	0.02	19.08*	17.07*	0.05	60.15*	12.24*	3.98	2.88	1.60	1.59	1.00
Fruits per plant	2.85	42.39*	17.98*	0.45	352.87*	14.11*	100.24*	8.38	2.50	-	-
Fruit yield per plant (g)	0.07	10183.51*	2586.46*	86.64*	103847.89*	6698.83*	46849.43*	15.27	54.44	901.26	1.27
Ridges per fruit	0.11	7.35*	8.54*	0.17*	1.42*	0.58*	7.60*	0.04	0.05	0.06	1.09
Dry matter (%)	0.03	3.14*	2.67*	2.38*	9.07*	1.51*	2.41*	0.40	0.16	-	-
Mucilage (%)	0.001	0.19*	0.21*	0.03*	0.17*	0.40*	0.71*	0.001	0.02	0.15	2.56

*Significant at P ≤ 0.05

Table 3: Estimates of general combining ability effects of lines (females) and testers (males) for fruit yield and horticultural traits in okra

Lines/Testers	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length	Fruit length	Fruit diameter	Average fruit weight	Plant height	Harvest duration	Fruits per plant	Fruit yield per plant	Ridges per fruit	Dry matter	Mucilage
Lines															
P-20	0.40	0.04	0.70*	0.77	-1.19*	-0.47	-0.10	-1.05	-14.70*	-3.30*	-0.17	-20.02*	0.07	-0.66*	-0.09*
VRO-4	-1.49*	-1.46*	-0.56*	0.17	0.22	0.43	-0.05	0.27	5.13	-1.05	0.46	12.30*	-0.10	-0.32	0.03
Parbhani Kranti	0.09	-1.46*	-0.53*	1.87	0.36	0.95*	0.11	2.75*	28.67*	-0.04	1.75	75.56*	-0.04	-0.92*	-0.31*
P-8	0.84	0.54	0.15	0.54	-0.72	-0.10	0.00	2.99*	-6.93*	1.52*	0.87	66.88*	-0.19*	-0.79*	0.16*
Tulsi-1	1.56*	1.54*	-0.21	1.27	-1.19*	-0.50	0.04	-0.40	-11.36*	0.58	1.29	7.29*	-0.28*	-0.04	0.03*
SKBS-11	-0.76	0.54	-0.46*	-1.64	3.66*	0.40	-0.01	1.48	54.32*	0.54	-0.69	13.18*	-0.04	-0.16	0.16*
VRO-6	-0.50	-1.46*	-0.16	2.79*	-1.58*	0.13	-0.05	-1.59	-7.06*	-2.22*	2.33	2.50	-0.14	0.37	0.41*
IC-169468	-2.07*	-1.46*	-0.91*	-0.34	0.03	0.13	-0.01	0.72	-5.33	2.03*	1.21	24.71*	-0.19*	0.35	0.18*
P-23	-2.22*	-1.96*	-0.06	-2.74*	-0.43	-0.45	-0.12	-1.47	-29.49*	1.11	-2.44*	-56.73*	-0.26*	-0.54*	0.06*
Japan Red	6.73*	5.04*	0.05	-3.64*	2.83*	0.30	0.05	-0.63	13.52	-1.19	-3.64*	-61.23*	1.25*	0.45	-0.40*
Japan 5 Ridged	-2.50*	0.04	-0.28	-0.09	-0.16	-0.72*	0.09	-2.08*	-3.96	0.61	0.44	-30.77*	-0.05	0.96*	-0.39*
Japan Round	-0.09	0.04	2.25*	1.04	1.82*	-0.11	0.05	-0.99	-22.83*	1.40*	-1.44	-33.67*	-0.02	1.29*	0.15*
SE (gi) ±	0.56	0.69	0.21	1.19	0.52	0.29	0.15	0.94	2.95	0.69	1.18	1.60	0.08	0.26	0.02
SE (gi-gj) ±	0.79	0.97	0.30	1.68	0.74	0.41	0.21	1.32	4.17	0.28	1.67	2.26	0.11	0.36	0.02
Testers															
9801	-0.96*	-0.79*	-0.09	-1.06*	-0.93*	0.30*	-0.11*	0.50	-27.56*	-0.57*	-0.84*	-2.43*	0.04	0.13	-0.04*
Hisar Unnat	0.96*	0.79*	0.09	1.06*	0.93*	-0.30*	0.11*	-0.50	27.56*	0.57*	0.84*	2.43*	- 0.04	-0.13	0.04*
SE (gi) ±	0.23	0.28	0.09	0.49	0.21	0.12	0.06	0.38	1.20	0.98	0.48	0.65	0.03	0.11	0.01
SE (gi-gk) ±	0.32	0.40	0.12	0.69	0.30	0.17	0.09	0.54	1.70	0.40	0.68	0.92	0.05	0.15	0.01

*Significant at P ≤ 0.05

Table 4: Estimates of SCA effects of different cross-combinations for fruit yield and horticultural traits in okra

Crosses	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Internodal length	Plant height	Harvest duration	Fruit yield per plant	Ridges per fruit	Mucilage
P-20 x 9801	- 0.26	- 1.71*	0.04	0.39	8.08	- 0.26	4.83*	-0.35*	0.02
P-20 x Hisar Unnat	0.26	1.71*	- 0.04	- 0.39	- 8.08	0.26	- 4.83*	0.35*	- 0.02
VRO-4 x 9801	0.29	0.79	0.19	- 0.52	- 13.53*	- 1.12	- 52.45*	0.11	- 0.13*
VRO-4 x Hisar Unnat	- 0.29	- 0.79	- 0.19	0.52	13.53*	1.12	52.45*	- 0.11	0.13*
Parbhani Kranti x 9801	- 0.62	- 0.21	0.16	0.81	0.61	- 0.85	- 5.85*	0.25*	0.25*
Parbhani Kranti x Hisar Unnat	0.62	0.21	- 0.16	- 0.81	- 0.61	0.85	5.85*	- 0.25*	- 0.25*
P-8 x 9801	1.29	1.79*	- 0.31	0.37	5.62	0.81	- 6.27*	0.10	0.24*
P-8 x Hisar Unnat	- 1.29	- 1.79*	0.31	-0.37	- 5.62	- 0.81	6.27*	- 0.10	- 0.24*
Tulsi-1 x 9801	1.01	- 0.21	0.24	0.38	1.64	0.29	32.44*	0.04	0.01
Tulsi-1 x Hisar Unnat	- 1.01	0.21	- 0.24	- 0.38	- 1.64	- 0.29	- 32.44*	- 0.04	- 0.01
SKBS-11 x 9801	- 1.78*	- 1.21	- 0.11	0.46	14.86*	0.72	23.03*	0.10	- 0.48*
SKBS-11 x Hisar Unnat	1.78*	1.21	0.11	- 0.46	- 14.86*	- 0.72	- 23.03*	- 0.10	0.48*
VRO-6 x 9801	- 0.38	- 0.21	- 0.01	0.84	14.74*	- 2.68*	- 2.47	- 0.15	0.11*
VRO-6 x Hisar Unnat	0.38	0.21	0.01	- 0.84	- 14.74*	2.68*	2.47	0.15	- 0.11*
IC-169468 x 9801	- 0.13	0.79	- 0.01	- 1.29	- 2.39	0.12	15.02*	0.01	- 0.02
IC-169468 x Hisar Unnat	0.13	- 0.79	0.01	1.29	2.39	- 0.12	- 15.02*	0.01	0.02
P-23 x 9801	- 0.77	0.29	- 0.11	0.39	- 0.33	1.00	1.73	- 0.13	- 0.42*

P-23 x Hisar Unnat	0.77	- 0.29	0.11	- 0.39	0.33	- 1.00	- 1.73	0.13	0.42*
Japan Red x 9801	- 0.15	- 0.71	0.79*	0.21	4.46	- 0.15	-16.97*	0.30*	- 0.24*
Japan Red x Hisar Unnat	0.15	0.71	- 0.79*	- 0.21	- 4.46	0.15	16.97*	- 0.30*	0.24*
Japan 5 Ridged x 9801	2.29*	1.29	0.32	- 1.74*	- 18.76*	0.70	5.49*	- 0.20	0.29*
Japan 5 Ridged x Hisar Unnat	- 2.29*	- 1.29	- 0.32	1.74*	18.76*	- 0.70	- 5.49*	0.20	- 0.29*
Japan Round x 9801	- 0.77	- 0.71	- 1.21*	- 0.32	- 14.99*	1.43	1.47	- 0.04	0.36*
Japan Round x Hisar Unnat	0.77	0.71	1.21*	0.32	14.99*	- 1.43	- 1.47	0.04	- 0.36*
SE (Sij) ±	0.79	0.97	0.30	0.74	4.17	0.28	2.26	0.11	0.02
SE (Sij-Skl) ±	1.11	1.37	0.42	1.04	5.89	1.39	3.19	0.16	0.03

*Significant at $P \leq 0.05$

Specific combining ability effects

Specific combining ability effects represent dominance and epistatic component of variation which are non-fixable and hence, sca studies would not contribute to the improvement in self-pollinated crops except where commercial exploitation of heterosis is possible. From the data it is quite evident that none of the hybrids were having higher sca effect for all the characters (Table 4). Out of 24 cross-combinations Japan 5 Ridged x Hisar Unnat (good × poor) for days to 50 per cent flowering; P-8 x Hisar Unnat (poor × poor) for days to first picking; Japan Round x 9801 (poor × average) for first fruit producing node; Japan 5 Ridged x 9801 (average × good) for internodal length; Japan 5 Ridged x 9801 (average × good) for plant height; VRO-6 x Hisar Unnat (poor × good) for harvest duration; VRO-4 x Hisar Unnat (good × good) for fruit yield per plant; P-20 x Hisar Unnat (average × poor) for ridges per fruit and SKBS-11 x Hisar Unnat (good × good) for mucilage displayed highest significant specific combining ability effects.

Majority of the cross-combinations exhibiting desirable sca effects, had at least one of the parent as good or average general combiner. Similar views had also been shared by Bhatt *et al*. (2015) [4], Patil *et al*. (2016) [19], Tiwari *et al*. (2016) [29] and Pandey (2017) [17]. The present findings reveal that it is not necessary that parents having higher estimates of gca effects would also give higher estimates of sca effects. Sometimes specific interaction effects (most likely complimentary) in poor × poor crosses may perform better than good × good, good × poor and average × poor combinations because of the prevalence of high magnitude of non-additive component for the superiority of pertinent cross-combinations. In case of cross-combination P-8 x Hisar Unnat (days to first picking); SKBS-11 x Hisar Unnat (plant height); Japan 5 Ridged x 9801 & P-20 x 9801 (fruit yield per plant); Japan 5 Ridged x 9801 & Parbhani Kranti x 9801 (mucilage) although significant sca effects were observed but these hybrids had both the parents as poor general combiners. These results are in agreement with those of Khanpara *et al*. (2009) [10], Tiwari *et al*. (2016) [29] and Pandey (2017) [17] who reported in okra that the superior hybrids need not necessarily have parents showing high GCA effects.

Table 5: Specific cross-combinations with high desirable SCA effects for fruit yield and related traits in okra.

Cross-combinations	*Per se* performance	Traits with high SCA effects
Parbhani Kranti x Hisar Unnat	326.66 g	Fruit yield per plant
P-8 x Hisar Unnat	318.40 g	Fruit yield per plant and days to first picking
VRO-4 x Hisar Unnat	310.00 g	Fruit yield per plant and mucilage

The combinations exhibiting high sca effects derived from good or average general combiners will be of main interest as they certainly perform better for a particular trait. The cross-combination Japan 5 Ridged x Hisar Unnat can be exploited to isolate transgressive segregants in early generations as they involve both parents with high GCA effects for early harvest. Specific cross-combinations with high desirable sca effects for fruit yield and related traits are presented in Table 5. The high significant positive sca effects for fruit yield per plant were recorded in Parbhani Kranti x Hisar Unnat followed by P-8 x Hisar Unnat and VRO-4 x Hisar Unnat. Breeding for homozygous lines by pedigree and back cross method could be used for partial exploitation of additive genetic variance. In order to exploit different type of gene actions in a population, breeding procedure which accumulates the fixable type of gene effects and at the same time maintains considerable heterozygosity for exploitation dominance gene effects might prove most beneficial for its improvement.

Conclusion

From the data presented in this study, it could be concluded that both additive and non-additive gene actions played the major role in the inheritance of various traits. Lines VRO-6, Parbhani Kranti, IC-169468 and P-23 exhibited good gca effects for yield and related traits and could be exploited in future breeding programs by adopting appropriate breeding strategy. Cross- combinations Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and VRO-4 x Hisar Unnat showed high sca effects as well as *per se* performance for fruit yield per plant. Therefore, these combinations can be exploited for the production of F_1 hybrids after further testing in multiple locations.

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