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

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Abstract: The present investigation was carried out to identify desirable parents and F_1 hybrids in okra by involving eight diverse parents in a diallel mating design excluding reciprocals. Genotypes i.e., P-20 and VRO-4 for earliness; 9801 for first fruit producing node (-0.085), internodal length (-0.659) and fruit length (0.201); HU for average fruit weight (0.603); Tulsi-I for nodes per plant (0.429), fruit length (0.271) and plant height (12.068) were found good general combiners appeared to be worthy of exploitation in future breeding. It is suggested that involving these lines, new genotypes may be developed through multiple crossing for isolating high yielding varieties. The cross combinations VRO-4 × HU, Tulsi-I × SKBS-11, P-20 × Tulsi-I and P-8 × Tulsi-I showed high SCA effects as well as per se performance for yield per plant. The crosses showing high SCA effects and per se performance for yield per plant suggested that these hybrids may be exploited in further breeding programme.

Keywords: *Abelmoschus esculentus,* Combining ability, Diallel analysis, Okra

INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench) is an important fruit vegetable crop of the tropical, sub-tropical and warmer parts of temperate regions of the world. The crop shows preference for the tropical and sub-tropical climates, and it is of tremendous significance as a vegetable in these areas (Oyetunde and Ariyo, 2014). It belongs to Malvaceae family and grown in *kharif* and *zaid* seasons. It is thought to have been originated in India (Zeven and Zukovasky, 1975). Its tender green fruits are used as vegetable and mature fruits, roots and stems are used in paper industry and clearing gur or raw sugar. Green fruits are rich in vitamins (C, A and B) and minerals (Ca, P, Mg and Fe). It is an interesting crop to the breeders and geneticists for its monoadelphous condition of the stamens and large flower amendable to easy emasculation and fruit bears large number of seeds. There is a need to increase overall production to meet the inflating demand. This can be accomplished either by increase in area under cultivation or raising the productivity. The increase in productivity can be achieved by adopting the high yielding F_1 hybrids. The success of a breeding programme depends upon the choice of suitable parents and their utilization by adopting an appropriate breeding method. The combining ability analysis has been extensively used to identify potential parents either to be used in the development of hybrids or recombinant breeding for getting elite purelines.

Among several techniques, diallel cross analysis is one of the most powerful tool for characterizing the genetic architecture of plant genotypes and estimating the GCA of parents and

selecting desirable parents and crosses with high SCA for the exploitation of heterosis (Reddy *et al.*, 2012; Ali *et al.*, 2013). Developing improved varieties with high yield potential is continuous process and for hybridization, the choice of parents is based on information on combining ability of parents. The concept of general combining ability (GCA) and specific combining ability (SCA) was given by Sprague and Tatum (1942). They further reported that GCA is dependent mainly on additive gene effects and additive × additive type of epistasis, whereas SCA includes both dominance and epistasis. According to them, the GCA is the average performance of line in a series of hybrid combinations, and the SCA refers to those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Griffing (1956) defined techniques for estimating the GCA and SCA effects under different situations. Keeping this in view, the experiment was designed to have information on general and specific combining ability estimated in okra through diallel mating.

MATERIALS AND METHODS

The material for the investigation comprised eight okra genotypes viz., P-20, 9801, VRO-4, Parbhani Kranti (PK), P-8, Hisar Unnat (HU), Tulsi-I and SKBS-11 (Table 1) which were maintained through selfing during 2011 and crossed in diallel mating design (excluding reciprocals) during 2012 to generate 28 F_1 hybrids. All the F_1's along with their parents and hybrid Tulsi, a standard check were evaluated in a Randomized Block Design with three replications during

summer-rainy season of 2013 at Experimental Farm of the Department of Vegetable Science and Floriculture, CSKHPKV, Palampur. The field is located at 32° 6' N latitude, 76° 3' E longitude and 1290.8 m altitude. The crop was raised in three rows of 2.5m length with inter and intra row spacing of 45cm and 15cm, respectively. The observations were recorded on five competitive plants in each entry and replication for the parameters *viz.*, days to 50% flowering, days to first picking, first fruit producing node, nodes per plant, internodal length (cm), average fruit weight (g), plant height (cm), harvest duration (days), fruits per plant and fruit yield per plant (g). For the parameters *viz.*, fruit length (cm) and fruit diameter (cm), a random sample of five fruits/entry/ replication was drawn from fourth and eighth pickings. The combining ability analysis was computed by method II (parents plus one set of crosses but no reciprocals), Model I (fixed effect Model) as described by Griffing (1956).

RESULTS AND DISCUSSION

Analysis of variance for combining ability for quantitative traits in okra: The analysis of variance for combining ability effects was carried out for all the twelve attributes in F_1 generation and the results are presented in Table 2. The mean square due to general combining ability (GCA) were found significant (P≤ 0.05) for all the traits, except for fruits per plant and fruit yield per plant, while mean square due to specific combining ability (SCA) were significant for most of the traits with few exceptions, *viz.*, average fruit weight and harvest duration. The significant

results indicated the presence of additive and non-additive gene action in the inheritance of various traits. Involvement of both additive and non-additive components of heritable variance was also reported by Reddy *et al.*, (2012) for number of branches per plant, internodal length, days to 50% flowering, first flowering node, first fruiting node, fruit length, fruit width, fruit weight, total number of fruits per plant, number of marketable fruits per plant, total yield per plant, marketable yield per plant and YVMV infestation on fruits and Bhatt *et al.*, (2015) for days to first flowering, days to first picking, plant height, number of nodes per plant, length of internode, number of primary branches per plant, stem girth, fruit girth, fruit weight, number of fruits per plant and fruit yield per plant.

Estimates of combining ability effects for quantitative traits in okra: General combining ability (GCA) studies have successfully led to making choice of suitable parents (Table 3). All the parents exhibited variable results for combining ability as no single parent exhibited significant (P≤ 0.05) GCA effects for all the traits. Genotype VRO-4 showed the highest GCA effects for days to 50% flowering, days to first picking, internodal length and harvest duration. It was observed that the parents P-20 for days to 50% flowering and fruit diameter; P-8 for first fruit producing node; HU for average fruit weight and Tulsi-I for nodes per plant, fruit length and plant height showed the highest general combining ability effects. The parent 9801 was good general combiner for first fruit producing node, internodal length and fruit length. Sig-

Table 1. Sources and characteristics of eight parental lines of okra (*A. esculentus*) used in half-diallel at Palampur, India.

S. No.	Parents	Fruit colour	Plant height	Source
1.	P-20	Dark green	Tall	CSKHPKV, Palampur, India
2.	9801	Dark green	Dwarf	CSKHPKV, Palampur, India
3.	VRO-4	Green	Dwarf	IIVR, Varanasi, India
4.	Parbhani Kranti (PK)	Dark green	Tall	MAU, Parbhani, India
5.	P-8	Green	Tall	PAU, Ludhiana, India
6.	Hisar Unnat (HU)	Dark green	Medium tall	CCS HAU, Hisar, India
7.	Tulsi-I	Green	Tall	CSKHPKV, Palampur, India
8.	SKBS-11	Green	Tall	SKUAST, Srinagar, India

Table 2. Analysis of variance for combining ability for quantitative traits in okra.

S. No.	Traits	Source	Mean sum of square		
			GCA	SCA	Error
		df	7	28	70
1.	Days to 50 % flowering		6.825*	2.732*	0.892
2.	Days to first picking		9.474*	2.848*	1.313
3.	First fruit producing node		0.278*	0.040*	0.021
4.	Nodes per plant		0.873*	1.011*	0.341
5.	Internodal length (cm)		3.499*	0.761*	0.115
6.	Fruit length (cm)		0.512*	0.266*	0.110
7.	Fruit diameter (cm)		2.655*	0.883*	0.300
8.	Average fruit weight (g)		1.453*	0.522	0.356
9.	Plant height (cm)		744.936*	281.754*	62.676
10.	Harvest duration (days)		14.422*	3.889	3.153
11.	Fruits per plant		0.633	1.692*	0.386
12.	Fruit yield per plant (g)		124.085	686.900*	178.912

*Significant at 5% level

Table 3. Estimates of general combining ability (GCA) effects of parents for quantitative traits in okra.

S.No.	Parents	Days to 50% flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length (cm)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Plant height (cm)	Harvest duration (days)	Fruits/plant	Fruit yield/plant (g)
1.	P-20	-1.175*	-1.124*	-0.098*	0.354*	-0.058	-0.094	-0.098*	-0.247	2.778	1.578*	0.257	1.201
2.	9801	0.092	-0.304	-0.085*	-0.133	-0.659*	0.201*	0.029	0.026	-10.406*	-0.075	0.007	0.414
3.	VRO-4	-1.175*	-1.297*	-0.135*	0.044	-0.960*	0.064	0.058*	-0.011	-12.543*	1.705*	0.291	5.014
4.	PK	0.058	0.322	-0.095*	0.081	0.148	0.088	0.024	-0.478*	2.764	-0.568	0.291	-0.829
5.	P-8	-0.008	-0.291	-0.138*	-0.096	-0.129	0.106	-0.001	-0.327	-2.803	0.522	-0.076	-5.086
6.	HU	0.392	0.546	0.045	-0.473*	0.280*	-0.392*	0.045*	0.603*	-0.933	-0.835	-0.209	3.028
7.	Tulsi-I	1.225*	1.706*	0.278*	0.429*	0.577*	0.271*	-0.045*	-0.067	12.608*	-1.752*	-0.279	-4.819
8.	SKBS-11	0.592*	0.443	0.228*	-0.208	0.801*	-0.243*	-0.012	0.502*	8.534*	-0.575	-0.283	1.077
	SE(gi)±	0.279	0.339	0.043	0.173	0.100	0.098	0.016	0.176	2.342	0.525	0.184	3.957
	SE(gi-gj)±	0.422	0.512	0.064	0.261	0.151	0.149	0.025	0.267	3.541	0.794	0.278	5.982
	CD	0.557	0.676	0.085	0.344	0.200	0.196	0.032	0.352	4.671	1.048	0.367	7.891

*Significant at 5% level

nificant GCA effects for days to first flowering, internodal length, number of fruiting nodes and fruit length in okra were reported by Reddy *et al.*, (2012), Kumar *et al.*, (2014) and Bhatt *et al.*, (2015).

Additive parental effects, as measured by GCA effects are of great practical use to the breeders whereas non-allelic interactions are impracticable and cannot be manipulated. On the basis of present study, it can be recommended to include the parents P-20, 9801, VRO-4 and HU for all the possible matings for selecting desirable transgressive segregants. An overall study of GCA revealed that none of parent was good combiner for all characters under investigation (Singh *et al.*, 2012; Kumar *et al.*, 2014 and Bhatt *et al.*, 2015), which is due to the different genetic make up of the parents included in the study.

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 in cases where commercial exploitation of heterosis is feasible. However, in the production of homozygous lines breeder's interest usually rests upon transgressive segregation shown in the crosses. The specific combining ability effects of crosses are presented in Table 4. It was observed that no single cross could reveal significant (P≤ 0.05) SCA for all the traits. In the present study, out of twenty eight cross-combinations P-20 × PK (good × average) for days to 50% flowering; VRO-4 × HU (good × average) for days to first picking; P-20 × SKBS-11 (good × poor) for first fruit producing node; VRO-4 × HU (average × poor) for nodes per plant; P-20 × SKBS-11 (average × poor) for internodal length; P-20 × P-8 (average × average) for fruit length; P-8 × Tulsi-I (average × good) for fruit diameter; HU × Tulsi-I (good × average) for average fruit weight; VRO-4 × HU (poor × average) for plant height; VRO-4 × HU (good × average) for harvest duration; VRO-4 × HU (average × average) for fruits per plant and fruit yield per plant displayed highest significant specific combining ability effects.

Majority of the cross-combinations exhibiting desirable SCA effects, had atleast one of the parent as good or average general combiner. Similar views had also been shared by Kumar *et al.*, (2005) and Singh *et al.,* (2012). 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, HU × SKBS-11 (internodal length) although the significant SCA effect was observed but, this hybrid had both the parents as poor general combiners. This observation corroborate the observations of Kumar and Pathania, (2011) and Singh *et al.*, (2012) who reported in okra that the supe-

Table 4. Estimates of specific combining ability effects (SCA) of crosses in F_1 generation for quantitative traits in okra.

Hybrids	Days to 50% flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length (cm)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Plant height (cm)	Harvest duration (days)	Fruits/plant	Fruit yield/plant (g)
P-20 × 9801	-1.037	0.283	-0.015	-0.221	1.019*	-0.081	0.017	-0.227	11.566	0.376	-1.171	-22.229
P-20 × VRO-4	-2.104*	-2.790*	-0.031	-0.264	-0.014	0.077	0.007	-0.257	-2.664	3.130	0.579	5.838
P-20 × PK	-2.670*	-1.477	-0.138	-0.034	-0.755*	-0.909*	0.042	-0.124	-11.204	2.603	0.812	11.248
P-20 × P-8	2.063*	1.870	-0.128	-0.191	0.266	1.125*	0.051	-0.041	1.463	-1.220	-0.155	-1.862
P-20 × HU	-2.337*	-1.834	0.322*	0.453	-0.707*	-0.307	-0.033	-0.271	-5.507	1.670	-0.155	-5.976
P-20 × Tulsi-I	0.163	0.940	-0.178	0.384	0.273	0.566	0.073	0.533	7.486	-1.414	2.149*	42.971*
P-20 × SKBS-11	2.130*	1.336	-0.361*	-0.179	-1.631*	-0.310	-0.092	-0.237	-23.974*	-0.990	-0.948	-19.292
9801 × VRO-4	2.630*	3.390*	0.289*	-0.044	0.437	0.405	-0.006	0.536	5.653	-2.817	-0.471	-1.642
9801 × PK	-2.270*	-2.630*	-0.085	-0.481	-0.724*	0.231	0.034	0.869	-13.954	1.256	0.129	13.668
9801 × P-8	0.463	0.383	-0.175	0.196	0.180	-0.814*	-0.087	0.086	4.313	-1.300	0.995	17.858
9801 × HU	1.396	0.746	-0.025	-2.127*	-0.326	0.094	-0.078	-0.444	-23.090*	-3.077	-1.571*	-33.056*
9801 × Tulsi-I	-1.437	-2.147*	0.009	-0.729	-1.113*	0.061	0.070	-0.174	-22.264*	3.240*	0.565	6.391
9801 × SKBS-11	-0.470	-0.550	-0.008	-0.059	0.227	0.928*	0.107*	0.289	2.676	2.396	0.835	18.494
VRO-4 × PK	1.996*	1.763	-0.001	-0.391	-0.726*	0.315	0.023	0.906	-13.417	-0.590	0.112	13.501
VRO-4 × P-8	0.063	0.310	-0.058	-0.881	-1.066*	-0.026	-0.002	0.056	-21.117*	0.386	-0.188	-2.976
VRO-4 × HU	-2.004*	-2.860*	0.025	2.296*	0.725*	0.132	-0.043	-0.174	32.546*	4.076*	2.745*	46.311*
VRO-4 × Tulsi-I	-0.170	-0.554	-0.208	-0.972	-0.106	0.139	0.022	-0.134	-11.560	-0.807	0.115	-0.109
VRO-4 × SKBS-11	-2.204*	-1.757	0.042	-0.769	-0.433	0.739*	0.007	0.526	-13.687	0.483	0.019	6.961
PK × P-8	0.163	1.023	0.369*	0.816	1.127*	-0.067	-0.095	0.523	24.510*	0.326	0.345	12.201
PK × HU	-1.237	-1.480	-0.181	0.059	-0.053	0.611*	-0.085	-0.474	-0.827	-0.250	0.545	4.054
PK × Tulsi-I	-0.404	0.693	0.019	-0.376	1.067*	0.411	-0.036	-0.604	10.800	1.066	1.115	9.268
PK × SKBS-11	0.896	1.156	-0.298*	0.461	0.477	-0.388	-0.063	-0.507	11.806	-2.710	1.319*	15.971
P-8 × HU	0.496	1.000	-0.105	0.236	-1.282*	0.353	-0.124*	-0.191	-13.527	-1.507	0.912	14.011
P-8 × Tulsi-I	-1.004	-1.627	-0.105	-0.566	-1.249*	-0.007	-0.146*	0.713	-23.000*	0.376	1.082	26.191*
P-8 × SKBS-11	-2.037*	-2.230*	-0.155	-1.629*	1.504*	-0.483	-0.133*	-0.557	0.473	1.133	-0.615	-16.872
HU × Tulsi-I	0.596	1.303	-0.188	0.011	1.271*	-0.395	0.125*	1.916*	16.663*	-1.967	-0.985	3.478
HU × SKBS-11	1.563	0.533	0.062	-1.152*	-0.712*	-0.257	0.025	0.146	-21.330*	0.490	-0.581	-8.486
Tulsi-I × SKBS-11	0.063	-0.160	0.162	2.163*	-0.286	-0.158	-0.009	1.249*	19.496*	-1.794	1.589*	44.028*
SE (Sij) ±	0.856	1.039	0.131	0.529	0.307	0.301	0.049	0.541	7.179	1.610	0.564	12.129
SE (Sij-Sik) ±	1.267	1.537	0.193	0.783	0.454	0.446	0.074	0.800	10.622	2.382	0.834	17.945
SE (Sij-Skl) ±	1.195	1.449	0.182	0.738	0.428	0.420	0.069	0.755	10.014	2.246	0.786	16.919
CD	1.708	2.072	0.260	1.056	0.612	0.601	0.099	1.079	14.318	3.211	1.124	24.190

*Significant at 5% level

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

Cross-combinations	*Per se* performance (Fruit yield/plant)	Traits with high SCA effects
VRO-4 × HU	270.93g	Fruit yield per plant, days to 50% flowering, days to first picking, nodes per plant, plant height, harvest duration and fruits per plant
Tulsi-I × SKBS-11	256.87g	Fruit yield per plant, nodes per plant, average fruit weight, plant height and fruits per plant
P-20 × Tulsi-I	255.93g	Fruit yield per plant and fruits per plant
P-8 × Tulsi-I	232.87g	Fruit yield per plant, internodal length and fruit diameter

rior hybrids need not necessarily have parents showing high GCA effects.

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 P-20 × VRO-4 can be exploited to isolate transgressive segregants in early generations as they involve both parents with high GCA effects for early harvest. Similarly, cross combinations (P-20 × PK, P-20 × HU, VRO-4 × SKBS-11 and VRO-4 × HU) may give transgressive segregants in the later generations if the additive effect of one parent and complimentary epistatic effects (if present in the cross) act in the same direction and maximize the desirable plant character. 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 VRO-4 × HU followed by Tulsi-I × SKBS-11, P-20 × Tulsi-I and P-8 × Tulsi-I. Breeding for homozygous lines by conventional pedigree and back cross method could be use only partial exploitation of additive genetic variance. In order to exploit different types of gene actions in a population it is suggested that a breeding procedure which may accumulate the fixable type of gene effects and at the same time maintains considerable heterozygosity for exploitation dominance gene effects might prove most beneficial to improve the population of okra.

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. P-20, 9801, VRO-4 and HU showed good general combining ability for most of the traits appear to be worthy for exploitation of segregation and varietal development. Cross combinations VRO-4 × HU, Tulsi-I × SKBS-11, P-20 × Tulsi-I and P-8 × Tulsi-I showed high SCA effects as well as per se performance for fruit yield per plant. Therefore, it would be worthwhile to use these crosses for improvement in fruit yield per plant.

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