

Original Research Article

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Multi-Environment Analyses of Genetic Components and Combining Abilities in Relation to Heterosis in Okra [*Abelmoschus esculentus* (L.) Moench]

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ABSTRACT

Genetically designed analyses for combining abilities, heterosis, genetic advance and heritability were made utilizing line x tester mating design having fourteen divergent parents under multiple environments. Significant mean squares for general combining ability (GCA) and specific combining ability (SCA) indicated joint role of additive and non-additive gene action for most of the characters. The predictability ratio of $\sigma^2_{gca} / \sigma^2_{sca}$ was less than 1 for all the characters showing preponderance of non-additive gene actions. Based on the GCA effects of parents, VIO 47672 among lines and GJO – 3 among testers were observed to be the best overall general combiners for yield and yield components. The outstanding five hybrids viz., VIO 47672 x GJO – 3, IC – 045796 x GJO – 3, IC – 111493 x GJO – 3, IC – 045796 x GAO – 5 and VIO 47672 x GAO – 5 were identified for developing high yielding F₁ hybrids of Okra with many desirable traits based on their SCA and heterosis effects. Assessment of heritability percentages in the narrow sense (h^2_{ns} ; %) for the various studied traits, were found to be within the range of 4.19% for the first flowering node to 46.33% for fruit weight. On the other hand GAM (%) ranged between 0.93% for the first flowering node and stalk length to 30.42% for the number of branches.

Keywords

Combining ability, Gene action, Heterosis, Multi-environment, Okra, Yield.

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Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is an economically important vegetable crop grown in tropical and sub-tropical parts of the world. India is a major okra producing country in the world comprising of 72% of total area under okra (FAOSTAT, 2013). Selection of suitable parents is an important step for enhancement of any breeding program for crop varietal improvement (Solankey *et al.*, 2016). The knowledge of

nature of gene action governing the expression of various traits could be helpful in predicting the effectiveness of selection (Dabhi *et al.*, 2010). The combining ability is the important genetic tool, which provides a guideline for an assessment of the relative breeding potential of the parents or identifying the best combiners, which may be hybridized either to exploit heterosis or to accumulate fixable genes (Katagi *et al.*,

2015). Exploitation of heterosis in okra has been recognized as a practical tool in providing the breeders a means of improving yield and other important traits (Lyngdoh *et al.*, 2013; Singh *et al.*, 2016). The success of a breeding programme is determined by useful gene combinations in the form of high combining inbred (Obiadalla *et al.*, 2013). Several researchers have reported the presence of heterosis for fruit yield in okra (Akotkar *et al.*, 2014; Badiger *et al.*, 2014; Katagi *et al.*, 2015; Kumar *et al.*, 2014; Flemine Xavier *et al.*, 2016; Maciel *et al.*, 2017). Several high yielding hybrids have been developed by Indian Institute of Vegetable Research (ICAR-IIVR), Varanasi, India among which “Kashi Bhairav” has achieved yield up to 20-22 MT/ha. Average productivity of okra in India is 11.35 MT/ha (Anonymous, 2016). A large potential yield gap exists between farmers’ yield and than that of documented by various research organizations. The major problem in okra cultivation is lack of high-yielding varieties/hybrids (Solankey *et al.*, 2016). The productivity of okra should be increased through hybridization and recombination. Yield barriers can be mitigated by planning effective breeding program involving best suitable combiner parents to develop high yielding hybrids. In this connection present study was taken to obtain clear and determined information about the relative importance of gene actions involved in the inheritance of some growth and yield traits of okra through the estimation of both the general and specific combining abilities in relation to heterosis over multiple environments using a line x tester approach.

Materials and Methods

The study was conducted between September, 2013 and February, 2015 (including crossing programme during September to December, 2013). The experiment consisting 55 genotypes including 14 parents their 40

hybrids and one standard check, was laid out in a randomized complete block design (RBD) with three replications over three environments (Table 1) at the Regional Horticultural Research Station, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari, situated at coastal region of South Gujarat. Geographically, it is situated at 20°- 37' N latitude and 72°- 54' E longitude with an altitude of 11.98 meters above the Mean Sea Level. All recommended horticultural practices along with plant protection measures were followed uniformly and timely.

Parental material and recorded data

Fourteen diverse parents (Table 2) were crossed to produce forty F₁ hybrids. Selfed truthful seeds treated with Thiram 4g/kg of seeds were sown (10 plants/row) in line x tester fashion at spacing of 60 x 45 cm in. Observations on thirteen traits were recorded. The crude fiber content from okra fruit was determined by the method as illustrated by Thimmaiah (1999).

Statistical analysis

The data were statistically analyzed, using Windostat version 8.6. The differences among the means of various yield components were tested, using Duncan’s Multiple Range Test (L.S.R.) at 0.05 level of probability.

Analysis of combining ability

The combining ability analysis was carried out as per the method given by Kempthorne (1957). The critical differences were calculated as advocated by Panse and Sukhatme (1967). The heritability percentage estimation and categorization (low, moderate and high) and narrow sense heritability estimation were calculated as suggested by Robinson *et al.*, (1955). Genetic advance in absolute unit (GA) and percent of the mean

(GAM at 5%), summing selection of superior 5% of the genotypes were estimated as the method illustrated by Jhonson *et al.*, (1955).

Results and Discussion

Analysis of variance of combing ability

The analysis of variance depicting mean squares is presented in Table 3. Pooled analysis of variance over environments revealed that all the three environments were different as estimates among them were found significant for all the traits. The differences among hybrids were highly significant for all the traits in individual and across the environments. The variance due to parents was further partitioned into variance due to interaction of females and males. The results revealed that mean squares due to males x females were highly significant for all traits across environments. The variance due to hybrids was highly significant for all the traits over the environments. The interactions of hybrids x environments and Female x Male x Environment were significant for all the traits except for the number of branches and fruit diameter which revealed that the hybrids, males and females were sensitive to the environments. In pooled analysis, significant environmental variances (σ^2_e) for all the traits not only signified the appreciable influence of environments on the expression of traits but also confirmed the fact that considerable differences existed among the environments under which the study was conducted.

Genetical analysis of various components

The results of genetical analysis of various components are presented in Table 4. The results illustrated that the estimated variances for the effects of both general and specific combining abilities ($\sigma^2_{gca}/\sigma^2_{sca}$) showed relatively high values for all the studied

characters. Moreover, it was noticed for all the characters that non-additive gene effects were found to be more pronounced for their contributions to the genetic variability. The estimates of h^2_{ns} % showed relatively low or low percentages for the all the characters except number of branches (31.46%), fruit diameter (39.47%) and fruit weight (46.33%). Similarly, the estimations of genetic advance as per cent mean, for the various characters studied, were found to be within the range of 0.93% for first flowering node to 30.42% for number of branches. All the characters studied exhibited relatively low GAM except number of branches (30.42%). In present investigation, none of the characters studied exhibited high heritability coupled with high genetic advance. The character number of braches exhibited moderate heritability coupled with high genetic advance. Significant results of various components indicated that males-females and parents-hybrids interacted significantly with each other. These results are in agreement with those of Das *et al.*, (2013) and Badiger *et al.*, (2014).

General and specific combining abilities estimates in relation to heterosis

The estimates of combining abilities (Table 5 and 6) showed that among lines, IC 045796 and VIO 47672 were found to be the most suitable combiners for most of the traits. Among testers GJO-3 was found to be the best combiners for most of the characters. Hybrids JOL-08-13 x Arka Anamika and VIO-44244 x Varsha Uphar registered highest significant SCA effects for earliness traits like days to first flowering (-1.98) and first flowering node (-0.53), respectively. Regarding plant growth characters like for number of branches and plant height VIO 44244 x Varsha Uphar (0.29) and VIO 47672 x GJO - 3 (18.28), registered highest significant SCA effects respectively.

Table.1 Details of environments taken under study

Environments	
E ₁	Summer, 2014 (February to May, 2014)
E ₂	Rainy, 2014 (June to September, 2014)
E ₃	Winter, 2014 – 15 (November, 2014 to February, 2015)

Table.2 Parental material used for the study

Parent Lines	Source/Origin
VIO 44244	AVRDC, Taiwan
IC – 111493	NBPGR, New Delhi, India
JOL – 08 – 13	Junagadh Agricultural University, Junagadh (Gujarat)
EC – 284327	NBPGR, New Delhi, India
IC – 045796	NBPGR, New Delhi, India
IC – 052273	Junagadh Agricultural University, Junagadh (Gujarat)
JOL – 10 – 18	Junagadh Agricultural University, Junagadh (Gujarat)
AOL – 09 – 17	Anand Agricultural University, Anand (Gujarat)
VIO 47672	AVRDC, Taiwan
EC – 305623	NBPGR, New Delhi, India
Testers	
GAO – 5	Anand Agricultural University, Anand (Gujarat)
GJO – 3	Junagadh Agricultural University, Junagadh (Gujarat)
Arka Anamika	IIHR, Bengaluru, India
Varsha Uphar	IIHR, Bengaluru, India
Commercial check: Sonakshi (Hybrid; Nunhems Company)	

Table.3 Analysis of variance for the yield components of the fourteen parents and their forty F₁ hybrids of okra across the environments

Source	Environments	Hybrids	Females (F)	Males (M)	Females x Male (F x M)	Hybrids x Environments	(Female x Male) x Environments
D.F.	2	39	9	3	27	78	54
Traits							
DFP	1272.9**	27.33**	43.99	28.92	21.61**	13.24**	14.50**
FFN	118.4**	0.95**	0.77	0.880	1.02**	1.02**	0.88**
IL	1279.5**	5.08**	6.04	10.58	4.16**	2.59**	2.541**
PH	456186.4**	604.8**	1110.47*	303.41	469.79**	294.9**	314.3**
NOB	0.46**	0.32**	0.59*	0.34	0.23**	0.052	0.043
NF	4334.2**	24.31**	45.19*	24.92	17.36**	8.41**	7.96**
FL	568.8**	2.33**	2.06	3.20	2.33**	0.61*	0.61*
FD	1.63**	0.08**	0.11	0.19*	0.05**	0.01	0.01
FW	430.63**	1.87**	2.87	4.20*	1.28**	0.47*	0.50*
FY	1073573.0**	6956.41**	12204.37*	9416.2	4933.77**	1946.0**	1806.4**
SL	0.44**	0.07**	0.14*	0.09	0.05*	0.04*	0.03*
CF	4.85**	0.88**	1.01	0.64	0.87**	0.41**	0.36**
SLD	21.13**	1.96**	3.07	0.96	1.71**	0.05**	0.05**

* and ** Significant at $P = 0.05$ and 0.01 probability level, respectively

Table.4 Estimates of various components of the total variance for the yield components of the fourteen parents and their forty F₁ hybrids of okra across environments

Estimates	Traits												
	DFE	FFN	IL	PH	NOB	NF	FL	FD	FW	FY	SL	CF	SLD
σ^2_e	7.815**	0.729**	7.893**	2815.129**	0.0026**	26.737**	3.506**	0.010**	2.655**	6625.005**	0.0026*	0.029*	0.130**
σ^2_{gca}	0.469	0.009	0.119*	9.071**	0.006**	0.507*	0.029	0.002*	0.047*	166.487**	0.0014*	0.012	0.031
σ^2_{sca}	1.640*	0.086*	0.377*	37.149**	0.021**	1.618**	0.172**	0.004**	0.083	512.467**	0.0025	0.091**	0.186**
$\sigma^2_{gca}/\sigma^2_{sca}$	0.285	0.104	0.315	0.244	0.285	0.313	0.168	0.500	0.566	0.324	0.560	0.131	0.166
$h^2_{ns}(\%)$	15.43	4.19	15.50	13.25	31.46	19.52	25.02	39.47	46.33	21.68	20.57	8.84	23.96
GAM (%)	1.69	0.93	4.49	2.31	30.42	5.61	2.26	5.92	3.97	9.05	2.09	1.88	7.27
Error	6.847	0.246	0.763	135.451	0.041	2.797	0.781	0.015	0.540	321.56	0.030	0.048	0.033

σ^2_{gca} = General combining ability variance.

σ^2_{sca} = Specific combining ability variance.

σ^2_e = Environmental variance

* and ** Significant at $P = 0.05$ and 0.01 probability level, respectively

Table.5 Estimates of general combining ability for the studied traits of the fourteen parents of okra over pooled environments

Parents	Traits												
	DFE	FFN	IL	PH	NOB	NF	FL	FD	FW	FY	SL	CF	SLD
Lines													
VIO 44244	0.30	0.16	-0.38**	-3.10	-0.13**	-1.63**	-0.20	-0.05*	-0.13	-21.27**	-0.06*	-0.04	0.06**
IC - 111493	-0.64	-0.12	0.13	3.41	0.06	0.69*	0.08	0.005	0.23	13.56**	-0.12**	-0.10**	0.53**
JOL - 08 - 13	0.27	0.13	-0.70	-5.75**	0.03	0.70*	-0.17	-0.03	-0.04	8.13**	0.03	0.17**	0.18**
EC - 284327	2.01**	0.17*	-0.20	-7.37**	-0.22**	-1.23**	-0.06	-0.07**	-0.39**	-22.18**	-0.06*	0.16**	-0.04
IC - 045796	-0.893*	-0.24**	0.58**	9.52**	0.11**	0.78**	0.28	0.07**	0.31*	16.45**	0.02	-0.23**	0.21**
IC - 052273	-0.77	0.05	0.15	-1.13	-0.03	-0.12	-0.09	0.001	-0.01	-2.88	-0.02	-0.07*	-0.31**
JOL - 10 - 18	-0.16	-0.09	-0.32*	-0.05	-0.04	-0.41	-0.12	-0.02	-0.07	-8.18**	0.03	0.26**	-0.35**
AOL - 09 - 17	-0.35	0.09	-0.02	1.40	0.08*	0.28	0.10	0.004	-0.10	1.37	0.04	0.11**	-0.39**
VIO 47672	-1.42**	-0.14	0.70**	7.45**	0.23**	2.01**	0.48**	0.12**	0.52**	33.91**	0.08**	-0.20**	0.15**
EC - 305623	1.66**	-0.01	-0.57**	-4.38*	-0.05	-1.04**	-0.28	-0.02	-0.33**	-18.92**	0.03	-0.03	-0.02
S.E.g _i	0.61	0.12	0.20	2.74	0.04	0.39	0.20	0.03	0.17	4.22	0.04	0.05	0.04
Testers													
GAO - 5	-0.22	-0.03	0.15	0.33	0.05*	0.22	-0.01	-0.001	0.07	4.58*	0.04*	0.06**	0.05**
GJO - 3	-0.69*	-0.13*	0.40**	2.20*	0.06*	0.57**	0.26**	0.06**	0.28**	11.58**	-0.001	-0.11**	0.11**
Arka Anamika	0.37	0.06	-0.27**	-2.44*	-0.07**	-0.64**	-0.18*	-0.03	-0.20*	-11.82**	-0.04*	0.06**	-0.11**
Varsha Uphar	0.54	0.10	-0.29**	1.97	-0.04	-0.15	-0.06	-0.04**	-0.15	-4.34*	0.01	-0.02	-0.05**
S.E.g _j	0.39	0.07	0.13	1.73	0.03	0.25	0.13	0.02	0.11	2.67	0.02	0.03	0.02
gi - gj (Line)	1.21	0.23	0.40	5.40	0.09	0.77	0.41	0.05	0.34	8.32	0.08	0.10	0.08
gi - gj (Tester)	0.76	0.14	0.25	3.41	0.05	0.49	0.25	0.03	0.21	5.26	0.05	0.06	0.05

gi - gj = differences between two (GCA) estimates of two lines and tester, respectively.

* and ** Significant at $P = 0.05$ and 0.01 probability level, respectively

Table.6 Promising parents, good general combiners, best performing hybrids and best specific crosses for different traits across the environments

Traits	Best performing parents		Good general combiners		Best specific crosses			S _{ij} - S _{ik}	S _{ij} - S _{kl}
	Parent	Mean	Parent	GCA effect	Cross	SCA effect	Combination		
DFE	Varsha Uphar	45.61	VIO 47672	-1.42**	JOL - 08 - 13 x Arka Anamika	-1.98**	Good x Poor	2.43	4.03
FFN	IC-111493	4.93	IC-045796	-0.24**	IC - 052273 x Varsha Uphar	-0.53**	Good x Poor	0.46	0.76
IL	JOL-08-13	7.98	EC-305623	-0.57**	IC - 052273 x GJO - 3	-1.49**	Good x Poor	0.81	1.34
PH	VIO 47672	135.47	IC - 045796	9.52**	VIO 47672 x GJO - 3	18.28**	Good x Good	10.80	17.92
NOB	JOL-08-13	2.47	VIO 47672	0.23**	VIO 44244 x Varsha Uphar	0.29**	Poor x Poor	0.18	0.31
NF	IC-045796	17.28	VIO 47672	2.01**	IC - 111493 x GJO - 3	2.10**	Good x Good	1.55	2.57
FL	Arka Anamika	11.15	VIO 47672	0.48**	JOL - 08 - 13 x Arka Anamika	0.73*	Poor x Poor	0.82	1.36
FD	1. VIO 47672 2. GAO - 5	1.56	VIO 47672	0.12**	1. JOL - 08 - 13 x Arka Anamika 2. IC - 111493 x GJO - 3	0.13**	1. Poor x Poor 2. Average x Good	0.11	0.19
FW	IC-111493	10.89	VIO 47672	0.52**	1. IC - 111493 x GJO - 3 2. JOL - 10 - 18 x Varsha Uphar	0.58**	1. Average x Good 2. Poor x Poor	0.68	1.13
FY	GAO-5	204.98	VIO 47672	33.91**	VIO 47672 x GJO - 3	36.00**	Good x Good	16.65	27.61
SL	EC-284327	2.23	IC- 111493	-0.12**	VIO 44244 x Arka Anamika	-0.11*	Good x Good	0.16	0.27
CF	EC-284327	4.22	IC-045796	-0.23**	VIO 44244 x GJO - 3	-0.48**	Average x Good	0.20	0.33
SLD	GAO-5	3.96	IC-111493	0.53**	VIO 47672 x Arka Anamika	0.70**	Good x Poor	0.16	0.28

S_{ij} - S_{ik}: Difference between two SCA of two hybrids, with a common parent. (L.S.D._{0.05})

S_{ij} - S_{kl}: Difference between two SCA of two hybrids, with non-common parent. (L.S.D._{0.05})

* and ** Significant at P = 0.05 and 0.01 probability level, respectively

Table.7 Promising heterotic crosses and their performance for fruit yield per plant and other related parameters

Hybrids	Fruit yield per Plant (g)	SCA effect	GCA effect		Standard Heterosis (%)	Yield attributing traits having significant and desirable heterosis over standard check
			P ₁	P ₂		
VIO 47672 x GJO - 3	278.01	1.77**	33.91**	11.58**	33.33**	NB, NF, DFF, PH, FL, FD, FW
IC - 045796 x GJO - 3	256.16	2.10**	16.45**	11.58**	22.83**	NB, NF, FL, FD, FW
IC - 111493 x GJO - 3	254.99	2.10**	13.56**	11.58**	22.27**	NB, NF, DFF, FFN, PH, FL, FD, FW, SL
IC - 045796 x GAO - 5	249.26	1.68**	16.45**	4.58**	19.52**	NB, NF, DFF, FL, FD, FW
VIO 47672 x GAO - 5	241.57	0.12	33.91**	4.58**	15.83**	NB, NF, DFF, PH, FL, FD, FW

* and ** Significant at P = 0.05 and 0.01 probability level, respectively

There is always a very strong and positive association of fruit yield with number of fruits, fruit length, fruit weight and fruit diameter. Highest and significant SCA effects were registered by IC – 111493 x GJO – 3 for number of fruits (2.10), JOL-08-13 x Arka Anamika for fruit length (0.73), JOL-08-13 x Arka Anamika and IC-111493 x GJO-3 for fruit diameter (0.13), IC-111493 x GJO-3 and JOL-10-18 x varsha uphar for fruit weight (0.58), VIO-47672 x GJO-3 for fruit yield (36.00), respectively. Das *et al.*, (2013), Akotkar *et al.*, (2014), Katagi *et al.*, (2015) and Wakode *et al.*, (2016) also reported similar results.

The estimates of GCA effects revealed that the parental lines showing high GCA effects for fruit yield per plant also exhibited high to average GCA effects for majority of its yield components. It was also interesting to note that involvement of parents with good GCA effects had resulted into hybrids expressing useful heterosis for various traits in majority of cases. The crosses exhibiting desirable and significant SCA and heterosis effects for fruit yield were also associated with high and favourable SCA effects for multiple yield contributing traits. The highest fruit yielding hybrid VIO 47672 x GJO – 3 (Good x Good) had significant desirable sca effect and standard heterosis as well for fruit yield and many of the yield components followed by the cross, IC – 111493 x GJO – 3 (Table 7). Corresponding to these findings, Das *et al.*, (2013) reported that positive sca effects were discernible in the hybrids involving both the parents possessing significant and positive GCA effects. The heterotic effects observed for fruit yield might have resulted from interaction of dominant genes contributed by both the parents. Hybrids involving both the parents possessing significant and positive GCA effects (good x good) with higher significant SCA effects for number of fruits per plant, fruit yield per plant and total fruit yield in okra have been reported by Aulakh *et*

al., (2012), Akotkar *et al.*, (2014) and Katagi *et al.*, (2015).

In conclusion, combining ability and heterosis estimates are potential tool for the enhancement of the breeding program in okra. On the basis of combining ability and heterosis estimates, hybrid VIO 47672 x GJO – 3 was identified as the best hybrid for fruit yield and its attributes. For fruit yield and its attributes, line VIO 47672 and tester GJO – 3 were the best combiners across the environments.

Abbreviations

D.F. = degree of freedom, GA= genetic advance, DFF= days to first flowering, FFN= first flowering node, IL= internodal length, PH= plant height, NOB= number of branches, NF= number of fruits, FL= fruit length, FD= fruit diameter, FW= fruit weight, FY= fruit yield, SL= stalk length, CF= crude fibre content and SLD= shelf life days, SCA/sca= specific combining effects, GCA/gca = general combining effects

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