Int.J.Curr.Microbiol.App.Sci (2020) *9*(9): 866-881

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 9 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.909.109

Estimation of Heterosis, Gene Action and Combining Ability over Environments for Improvement of Fruit Yield and its Related Traits in Okra [*Abelmoschus esculentus* (L.) Moench]

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Keywords

Heterosis, Gene interaction, Combining ability, Line x Tester analysis, okra [*Abelmoschus esculentus* (L.) Moench]

Article Info

Accepted:
10 August 2020
Available Online:
10 September 2020

A B S T R A C T

The present investigation was carried out to study heterosis, combining ability and gene interactions over environments of parents and their crosses in *kharif* 2018. The experimental material, consisting of eleven lines, five testers and their resultant 55 hybrids along with a commercial hybrid check 'OH-102' of okra were sown in three different locations of south Gujarat viz., College farm, NMCA, NAU, Navsari (E1), Cotton Research Sub Station, NAU, Achhalia (E2) and Regional Rice Research Station, NAU, Vyara (E3). Observations on sixteen traits were recorded for each and every location. The analysis of variances for individual as well as pooled over environments revealed considerable genetic variation present among the parents and their hybrids for all the traits under study. The hybrids *viz.*, JOL-14-10 X Arka Abhay, JOL-14-10 X GJO-3 and JOL-13-05 X GJO-3 exhibited higher but non-significant standard heterosis for fruit yield at all locations. Non-significant but desirable standard heterosis for fruit yield and its component traits suggested that there is no scope of exploiting heterosis commercially, but the possibility of isolating desirable segregants among these hybrid combinations. The higher magnitude of non-additive variance was higher for fruit yield and its contributing traits revealed the preponderance of non-additive gene action for the majority of the traits, hence these traits can be improved through recurrent selection for specific combining ability or through heterosis breeding program. The estimates of *gca* effects indicated that parents *viz.*, JOL-14-10, GJO-3 and JOL-13-05 were good general combiners for fruit yield and its contributing traits. None of the hybrids exhibited higher *per se* performance, *sca* effects and standard heterosis for fruit yield for all locations.

Introduction

Okra (*Abelmoschus esculentus* [L.] Moench) is an annual vegetable crop grown in tropical and subtropical regions of the world. It is quite popular in India because of easy cultivation, dependable yield and adaptability to varying moisture conditions. It is essentially a native of Africa but a few wild types have also been found in India. It belongs to genus *Abelmoschus* of family Malvaceae. Varying number of chromosomes ranging from 2n = 56 to 2n = 199 were reported by several workers in okra (Anon., 2011). It is a polyploid, with most observed chromosome number of 2n = 130 and an often cross pollinated crop, a highly variable cross pollination rate from 0 to 69% has been recorded for *A. esculentus* (Charrier, 1984). Considering the potentiality of this crop there is a prime need for its improvement and to develop varieties and hybrids suitable for specific agro-climatic zones. An important challenge would be to develop a variety/hybrid which responds well to resources and should be resistant to yellow mosaic virus and enation leaf curl virus also. To exploit the heterosis for potential yield components, knowledge of genetic architecture of fruit yield and its attributes is important in crop improvement.

Without a broad genetic base of heterogeneous plant material, it is impossible for plant breeders to produce cultivars that meet the changing needs regarding adaptation to growing conditions, resistance to biotic and abiotic stresses, product yield or specific quality requirements (Friedt *et al.,* 2007). Therefore, availability of genetic diversity is the pre-requisite for the success of any crop improvement program. Genetic diversity either exists naturally in the gene pool or it is created artificially by using different methods (Poehlman and Sleper, 1995). The knowledge of heterosis, combining ability and nature of gene action for various traits could be helpful in predicting the effectiveness of selection and very useful for understanding the course of evolution in the varieties. 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. For developing promising varieties through hybridization, the choice of parents is a matter of great concern to the plant breeder. A high yielding genotype may or may not transmit its superiority to its progenies. Therefore, the success of a breeding programme is determined by useful gene combinations in the form of high combining inbred. The occurrence of heterosis is common in plant species, but its level of expression is highly variable. Hybrid vigor in okra has been first reported by Vijayaraghavan and Warier (1946). For a sound hybridization program parents should be selected not only on the basis of their diversity but also on the basis of their combining ability effects. Knowledge on combining ability is useful for selection of desirable parents for exploitation of hybridity and transgressive expressions. Combining ability studies also give idea about the nature and magnitude of gene action and gene interactions involved in the inheritance of okra fruit yield and its related characters. The knowledge of nature of gene action governing the expression of various traits could be helpful in predicting the effectiveness of selection. The efficient partitioning of genetic variance into its components *viz*; additive, dominance and epistatis will help in formulating an effective and sound breeding programme. Several approaches are available for assessing the parents and cross combinations with respect to combining ability. Among these, Line x Tester analysis technique proposed by Kempthorne (1957) is popular and systematic approach for identification of superior parents and crosses, which is the basic requirement of success in any hybridization breeding programme.

Materials and Methods

The experimental material consists of 11 advanced breeding lines viz., AOL-12-52, AOL-12-59, AOL-13-73, AOL-12-144, AOL-12-133, AOL-14-32, JOL-69-05, JOL-11-12, JOL-13-05, JOL-14-10 and JDNOL-11-12 and five testers viz., GJO-3, GAO-5, Parbhani

Kranti, Arka Anamika and Arka Abhay. A total 55 F_1 hybrids were derived by crossing 11 lines and 5 testers using Line × Tester mating design during *Kharif* 2017 at Regional Horticulture Research Station, Navsari Agricultural University, Navsari, Gujarat. The 55 F_1 hybrids and their 16 parents were evaluated along with one commercial check (OH 102) in a randomized block design (RBD) with replicated thrice at different locations *viz.,* College farm, N. M. College of Agriculture, Cotton Sub-Research Station, Achhalia and Regional Rice Research Station, Vyara, Navsari Agricultural University, Navsari (Gujrat) during *kharif* 2018. Each entry was sown in a single row plot of ten plants, spaced 60 x 30 cm. Five plants were randomly selected for each genotype from each replication and evaluated for all the qualitative as well as quantitative characters such as days to 50% flowering, first flowering node, internodal length (cm), branches per plant, fruits per plant, plant height (cm), days to first picking, days to last picking, fruit length (cm), fruit diameter (mm), stalk length (cm), fruit weight (g), seeds per fruit, 100-seed weight (g), fruit yield per plant (g) and fiber content (%) were recorded from 16 parents and 55 F_1 hybrids. The mean values of the data recorded were subjected to Line X Tester analysis and magnitude of gene action and the combining ability analysis was carried out as per the method given by Kempthorne (1957) and Singh (1973) in individual as well as pooled over environments, also estimate the interaction of general and specific combining ability effects with environments among parents and hybrids, respectively using statistical software INDOSATE, Department of Genetic & Plant Breeding, Navsari Agriculture University, Navsari, Gujarat, India. Magnitude of heterosis was calculated as per standard procedure and significance of heterosis was worked out using the formula suggested by Wynne *et al* (1970).

Results and Discussion

Magnitude of economic heterosis

The utility of hybrid breeding approach lies in the identification of most heterotic and useful cross combination in order to make commercial cultivation of hybrids beneficial. In present investigation, hybrids *viz.,* JOL-14-10 X Arka Abhay at Navsari, JOL-14-10 X GJO-3, JDNOL-11-12 X GAO-5 and AOL-12-52 X Arka Anamika at Achhalia and JOL-13-05 X GJO-3 and AOL-12-144 X GJO-3 at Vyara were most promising for fruit yield per plant are depicted in Table 1 along with their mean performance, heterotic effects and *gca* and *sca* effects. Component wise examination of the hybrids (Table 1) revealed that best hybrids showed positive but non-significant standard heterosis for fruit yield per plant and its attributed traits like branches per plant, plant height, fruits per plant (except Achhalia), fruit length, fruit diameter, fruit weight, internodal length and days to last picking (except Achhalia) in each individual location, indicated that yield contributing traits were less contributing to fruit yield per plant and due to this reason top yielding hybrids at Navsari, Achhalia and Vyara exhibited poor and low heterotic response over standard check. The Probable explanation for these non-significant and non-heterotic hybrids were, may be ascribed to the cancellation of positive and negative effect shown by the parents involved in a cross combinations and can also happen when the dominance is not unidirectional (Gardner and Eberhart, 1966; Mather and Jinks, 1982). It was observed that not all yield contributing traits equally contributed towards heterosis, because the component traits competed for the sum total of metabolic substances produced by the plant and the conditions which favored the development of one component could have adversely affected the other one. Therefore, to obtain maximum yield in a selection programme desired levels of each component need to be known (More, 2015 and Satish *et al.*, 2017). In the present study, the heterotic performance was may be highly affected by the genetic background of parental genotypes also. Similar results were reported by Medagam *et al.*, (2013), Solankey *et al.*, (2013), Tiwari *et al.*, (2015), Verma and Sood (2015), Satish *et al.*, (2017) and Kerure and Pitchaimuthu (2018). The manifestation of undesirable heterosis observed in some of the hybrids for different traits may be due to the combination of the unfavorable genes of the parents (Medagam *et al.*, 2013). All the mean based top hybrids JOL-14-10 X Arka Abhay at Navsari and JDNOL-11-12 X GAO-5 and AOL-12-52 X Arka Anamika at Achhalia, depicted significant positive *sca* effects for fruit yield per plant indicated involvement of non-additive gene action in the heterotic response of these hybrids (Satish *et al.*, 2017). Beside high *sca* effects, none of the hybrid exhibited significant and positive heterosis in each location for fruit yield per plant. Top high heterotic crosses for fruit yield involved good x poor combination at Navsari, good x good combination at Achhalia and Vyara (Table 1). The Probable explanation for this type of behavior stands from the fact that poor yielding parents could have different constellation of genes were showing complementary interaction when brought together in hybrid combination (Das *et al.*, 2013).

It is clear from the above discussion that the non-significant and desirable heterosis over standard check for fruit yield and its component traits suggested that there is no scope of exploiting heterosis commercially, but possibility of isolating desirable segregants among this hybrid combination. Manifestation of heterosis for all the traits in single cross may not be possible, but the exploitation of hybrid vigor in one or more yield-attributing traits will significantly improve the crop performance over existing hybrid or variety (Hosamani *et al.*, 2008). While formulating suitable breeding methodology for the improvement in this crop, attention must be paid for the improvement of visual appearance as well as the biochemical qualitative aspects too, besides the productivity.

Combining ability studies

ANOVA for combining ability and gene action

Analysis of variance for combining ability over the environments (Table 2 and 3) revealed that mean squares due to environment were highly significant for all the traits (except fruit diameter and fiber content), which indicated considerable differences among the environments under which the study was conducted and suggested the influence of environments on inheritance of these characters. The mean squares due to females were significant for days to 50 % flowering at Navsari and in pooled analysis; branches per plant at Vyara; fruits per plant at Achhalia and in pooled analysis; plant height at Achhalia and in pooled analysis; days to first picking at Navsari and in pooled analysis and seeds per plant at Navsari and Vyara.

The mean square due to males was significant for only three traits like fruits per plant and fruit yield under individual and in pooled over the environments and fruit diameter at Achhalia and Vyara. Significant both females and males suggested its significant contribution in favour of general combining ability (*gca*) variance towards these traits and contributed towards additive genetic variance. The mean squares due to females x males were manifested highly significant by all the traits in individual as well as pooled over environment, it suggested its significant contribution in favor of specific combining ability (*sca*) variances and the result thus indicated that females behave differently with different males or *vice-versa*. This indicated that it contributed towards non-additive genetic variance.

The sensitivity of both *gca* and *sca* variances for environmental variations indicated that evaluation of genotypes in multi-location trials would be essential for estimating these variances with reliable precision. In present study, both *gca* and *sca* variances were significant for majority of the characters studied suggested that both additive and non-additive variances were important in the expression of these traits. However, scrutiny of $\sigma^2 gca/\sigma^2 sca$ ratio in individual as well as pooled over environments, revealed preponderance of non-additive gene action for all the traits except fruit diameter at Vyara and in pooled analysis and 100 seed weight at Navsari.

The importance of non-additive genetic variances for fruit yield per plant has been reported by several workers such as Oyetunde and Ariyo (2014), Bhat *et al.,* (2015), More *et al.,* (2015) and Makdoomi *et al.,* (2018). Fruit diameter at Vyara and in pooled analysis and 100 seed weight at Navsari was revealed preponderance of both additive and non-additive gene action for expression of these traits. From the present results, it was evident that the non additive gene action had greater role in the expression of all the traits under study, hence, merely selection will result no or slow for genetic improvement. Successful breeding methods are those that accumulate the genes to form superior gene constellations interacting in a favorable manner. The importance of non additive gene action for all yield components and quality traits in the present study indicated that important of recurrent selection for specific combining ability for improving these traits in okra.

Estimates of general combining ability effects

Nature and magnitude of combining ability effects helps in identifying superior parents and their utilization in further breeding programme. The parents classified as good, average and poor combiners based on estimates of general combining ability (*gca*) effects in individual as well as pooled over environment basis for various traits. In the present study, significant *gca* effects were observed for majority of the traits studied in each individual environments. None of the parent exhibited significant and desirable *gca* effects for all the traits. The analysis revealed that among parents, JOL-14-10, GJO-3, JOL-69-05 and Arka Anamika at Navsari; JOL-14-10, GJO-3, JDNOL-11-12 and Arka Anamika at Achhalia, GJO-3, JOL-13-05, JDNOL-11-12, GAO-5 and Arka Anamika at Vyara and GJO-3, JOL-14-10, JOL-13-05, JDNOL-11-12, Arka Anamika, JOL-69-05 and GAO-5 in pooled analysis exhibited significant and positive *gca* effects for fruit yield per plant. The parents, GJO-3 and Arka Anamika at Navsari, Achhalia and Vyara and in pooled analysis; JOL-14-10 at Navsari, Achhalia and in pooled analysis; JDNOL-11-12 at Achhalia, Vyara, and in pooled analysis reported significant *gca* effects in individual as well pooled over location indicated that general combining ability of these parents were less influenced by environment. The parent JOL-14-10 exhibited higher *gca* effects for fruit yield per plant was also exhibited significant *gca* effects for fruit per plant, days to 50 % flowering and days to first picking at Navsari. The same parent also exhibited highest significant *gca* effects for fruit yield per plants, fruit per plant, days to 50 % flowering, days to first picking and seeds per fruits at Achhalia. The parent GJO-3 exhibited higher *gca* effects for fruit yield per plant was also exhibited significant *gca* effects for intermodal length, fruits per plant and plant height at Vyara and the same parent also exhibited highest significant *gca* effects for fruit yield per plants, fruit per plant, first flowering node and plant height in pooled over the environments.

In present investigation, estimates of *gca* effects of 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. Similar results was reported by Medagam *et al.,* (2012), Das *et al.,* (2013), Katagi *et al.,* (2015), More *et al.,* (2017) and Satish *et al.,* (2017).

The estimates of *gca* effects also revealed that none of the parents showed consistently significant and desirable *gca* effects for all the traits (Bhatt *et al.,* 2015, More *et al.,* 2017 and Makdoomi *et al.,* 2018). Parents with superior combining ability can be intensively used in the hybridization programme aimed at amelioration of fruit yield. In order to synthesize dynamic population with most of the favourable genes accumulated, it will be pertinent to make use of the aforesaid parents which were good general combiners for several traits in a multiple crossing programme. Patil (2013) reported that involvement of parents with good *gca* effects had resulted into hybrids expressing useful heterosis for various traits in majority. But in present investigation, parents those are involved in top hybrids for yield were good general combiner did not resulted into useful heterosis.

Estimates specific combining ability effects

Top four hybrids for fruit yield per plant *viz.,* JOL-13-05 X Parbhani Kranti, AOL-14-32 X Parbhani Kranti, JOL-11-12 X Arka Anamika and AOL-13-73 X GJO-3 at Navsari; AOL-14-32 X Parbhani Kranti, AOL-12-59 X Arka Abhay, AOL-12-133 X Parbhani Kranti and JOL-11-12 X GAO-5 at Achhalia; AOL-14-32 X Parbhani Kranti, JOL-13-05 X Parbhani Kranti, AOL-12-59 X Arka Abhay and AOL-12-144 X Arka Abhay at Vyara and AOL-14-32 X Parbhani Kranti, AOL-12-59 X Arka Abhay, AOL-12-144 X Arka Abhay and JOL-11-12 X Arka Anamika in pooled analysis exhibited higher *sca* effects.

Considering the overall performance of the hybrids in individual and over the environments with respect to fruit yield per plant; a total of nine, eleven, four and ten hybrids displayed positive and significant *sca* effects at Navsari, Achhalia, Vyara and in pooled analysis, respectively.

For various yield components significant and desirable *sca* effects were noticed in several hybrids for number of days 50% flowering (one, sixteen, six and four), for inter nodal length (nine, two, seven and seven), for branches per plant (nine, five, four and seven), for fruits per plant (ten, fourteen, four and thirteen), for plant height (three, eight, five and four), for days to first picking (one, fifteen, five and four), for days to last picking (three, eight, two and three), for fruit length (thirteen, eight, nine and nine), for fruit diameter (five, seven, two and four), for fruit weight (one, three, one and four), for stalk length (two, two, nine and five), for seeds per fruit (zero, three, one and five), for 100 seed weight (one, five, zero and two) and for fiber content (three, six, ten and nine) at Navsari, Achhalia, Vyara and in pooled analysis, respectively. The estimates of *sca* effects revealed that none of the hybrids exhibited consistently significant and desirable *sca* effects for all the traits. Similar result was reported by Poshiya and Shukla (1986), Balakrishnan *et al.,* (2009) and Kayande *et al.,* (2018).

Table.1 Promising hybrids for fruit yield per plant with standard heterosis, *gca* effects, sca effects and component traits showing significant desired heterosis at Navsari, Achhalia and Vyara

Sr. No.	Hybrid	Fruit yield per plant (g)	Standard heterosis (%) over check OH-102 (304.18)	*gca* effects		*sca* effects	Useful and significant for component traits Standard heterosis (%)
				P_1	P_2		
NAVSARI							
1.	JOL-14-10 X Arka Abhay	310.96	2.23 (A)	34.462** (G)	-7.251 (P)	32.514* (G)	Stalk length
ACHHALIA							
1.	JOL-14-10 X GJO-3	335.60	8.64 (A)	37.901** (G)	29.775** (G)	19.372 (A)	Seeds per fruit, fruits per plants and days to last picking
2.	JDNOL-11-12 X GAO-5	320.34	3.70 (A)	22.792** (G)	3.061 (A)	45.932** (G)	Stalk length and Fiber content
3	AOL-12-52 X Arka Anamika	310.22	0.42 (A)	9.714 (A)	9.511* (G)	42.439** (G)	Seeds per fruit and fruits per plants
VYARA							
1.	JOL-13-05 X GJO-3	282.84	3.69 (A)	22.572** (G)	25.414** (G)	9.846 (A)	First Flowering node
2.	AOL-12-144 X GJO-3	275.07	0.84 (A)	-1.412 (G)	25.414** (G)	15.266 (A)	Fiber content

G: (Good) Significant in desired direction, A: (Average) Non significant but in desired direction and P: (Poor) Significant or Non-significant in undesired direction

Table.2 ANOVA for combining ability and estimates of genetic components of variance for pooled over environments

Source		Days to 50% flowering	First flowering node	Inter nodal length (cm)	Branches per plant	Fruits per plant	Plant height (cm)	Days to first picking	Days to last picking
Environments	2	581.309**	19.449**	108.638**	43.341**	176.411**	16255.785**	592.363**	293.111**
Replication	2	0.224	1.598**	1.507	0.626**	1.299	522.822**	0.336	0.190
Hybrids	54	30.176**	0.993**	2.772**	0.633**	74.337**	476.781**	24.509**	20.156**
Females (F)	10	93.568**	0.397	0.772	1.123	115.234*	1034.162**	70.971**	7.573
Males (M)	4	11.441	0.353	4.056	0.330	259.091**	399.888	10.241	28.631
Females x Males (F x M)	40	16.201**	1.205**	3.143**	0.541**	45.637**	345.126**	14.320**	22.454**
Hybrids x Environments	108	26.062**	1.021**	2.000**	0.467**	8.544**	259.146**	24.082**	28.223**
Female x Environment	20	28.154	1.626*	1.911	0.547	3.855	374.420	22.008	26.583
Male x Environment	8	8.875	0.518	2.183	0.330	3.755	147.416	7.892	26.868
(F x M) x Environments	80	27.258**	0.921**	2.004**	0.461**	10.196**	241.500**	26.220**	28.768**
Pooled Error	324	5.315	0.333	0.575	0.117	3.006	110.208	5.387	11.021

Estimates										
σ^2_f			1.961**	0.001	0.004	0.022	2.494*	20.532**	1.457**	1.457
σ^2_m			0.062	0.000	0.035	0.002	2.587**	2.926	0.049	0.049
σ^2_{fm}			1.210**	0.097**	0.285*	0.047**	4.737**	11.5139**	0.993**	1.270**
σ^2 gca			0.626	0.001	0.026	0.009	2.558**	4.8956	0.489	0.098
σ^2 sca			1.210**	0.097**	0.285*	0.047**	4.737**	11.5139**	0.993**	1.270**
σ^2 gca/ σ^2 sca			0.517	0.010	0.091	0.191	0.540	0.425	0.492	0.077
Contribution (%)	F		57.420	7.410	5.156	32.840	28.710	40.168	53.624	6.958
	M		2.810	2.635	10.840	3.860	25.820	6.213	3.095	10.522
	F x M		39.770	89.955	84.004	63.300	45.480	53.620	43.280	82.520
*** and ** Significant at 5 % and 1 % level of probability, respectively**										

Table.3 ANOVA for combining ability and estimates of genetic components of variance for pooled over environments

Source			**Fruit length (cm)**	**Fruit diameter (cm)**	**Stalk length (cm)**	**Fruit weight (g)**	**Seeds per fruit**	**100 seed weight (g)**	**Fruit yield per plant (g)**	**Fiber content**
Environments		2	167.147**	0.027	0.066*	355.175**	338.488**	1.344*	34367.157**	0.026
Replication		2	0.760	0.033*	0.049**	0.883	39.704	0.228	213.449	0.040
Hybrids		54	4.549**	0.020**	0.031**	7.447**	76.743**	0.542**	10863.951**	0.472**
Females (F)		10	5.347	0.023	0.015	11.572	101.956	0.507	12842.948	0.378
Males (M)		4	2.444	0.027	0.010	4.455	83.398	1.149	48288.648**	0.515
Females x Males (F x M)		40	4.560**	0.018**	0.038**	6.715**	69.774**	0.490**	6626.732**	0.491**
Hybrids x Environments		108	3.970**	0.024**	0.038**	1.939	32.962*	0.374	1592.269**	0.316**
Female x Environment		20	5.333	0.020	0.040	1.092	66.155**	0.157	1283.639	0.212
Male x Environment		8	3.536	0.061**	0.037	4.072*	23.054	0.431	433.939	0.139
(F x M) x Environments		80	3.673**	0.021**	0.038**	1.938	25.654	0.423*	1785.259**	0.360**
Pooled Error		324	0.8749	0.010	0.011	2.473	24.451	0.296	623.431	0.069
Estimates										
σ^2_f			0.099	0.000	0.000	0.202	1.722	0.005	271.545	0.007
σ^2_m			0.016	0.000	0.000	0.020	0.595	0.009	481.467**	0.005
σ^2_{fm}			0.409**	0.001**	0.003**	0.471**	5.036**	0.022**	667.034**	0.047**
σ^2 gca			0.042	0.001**	0.000	0.077	0.948	0.007	415.866**	0.005
σ^2 sca			0.409**	0.001**	0.003**	0.471**	5.036**	0.022**	667.034**	0.047**
σ^2 gca/ σ^2 sca			0.103	1.000	0.000	0.163	0.188	0.318	0.623	0.106
Contribution (%)	F		21.769	21.800	8.908	28.777	24.600	17.337	21.890	14.842
	M		3.979	10.232	2.256	4.432	8.050	15.706	32.920	8.082
	F x M		74.252	67.967	88.837	66.791	67.340	66.957	45.180	77.076
*** and ** Significant at 5 % and 1 % level of probability, respectively**										

Table.4 Best general combiner and best specific combining crosses along with their *per se* performance as well as best heterotic crosses for different traits at Navsari

Sr. No.	Traits	Best performing parents		Good general combiners		Best cross *per se*		Most heterotic cross over check "OH-102"		Best specific crosses		
		Parent	Mean	Parent	*gca* effect					Cross	*sca* effect	Combination
1	**Days to 50% flowering**	JOL-69-05	**41.67**	AOL-14-32	**-2.121****	AOL-14-32 x Prabhani Kranti, AOL-14-32 X Arka Abhay, , JOL-14-10 X Parbhani Kranti and JOL-14-10 X Arka Anamika	**40.33**	AOL-14-32 X Parbhani Kranti, AOL-14-32 X Arka Abhay, JOL-14-10 X Parbhani Kranti and JOL-14-10 X Arka Anamika	**-11.03***	AOL-12-52 X GJO-3	**-3.89****	**Poor x Poor**
2	**First flowering node**	AOL-12-144	**3.00**	JOL-69-05	**-0.354****	JOL-11-12 X GAO-5	**3.13**	JOL-11-12 X GAO-5	**-30.88****	AOL-12-144 X GAO-5	**-0.953****	**Poor x Average**
3	**Inter nodal length (cm)**	AOL-12-59	**9.27**	AOL-12-133	**-0.358***	AOL-14-32 X Arka Anamika	**7.80**	AOL-14-32 X Arka Anamika	**-17.02****	AOL-14-32 X Arka Anamika	**-1.552****	**Average x Average**
4	**Branches per plant**	Arka Abhay	**3.17**	AOL-13-73	**0.270****	AOL-12-144 X Arka Abhay	**3.67**	AOL-12-144 X Arka Abhay	**34.15****	AOL-12-144 X Arka Abhay	**0.868****	**Average x Average**
5	**Fruits per plant**	JDNOL-11-12	**19.67**	JOL-14-10	**2.256****	AOL-12-144 X Arka Abhay	**23.53**	AOL-12-144 X Arka Abhay	**13.50**	JOL-13-05 X Parbhani Kranti	**6.024****	**Average x Poor**
6	**plant height (cm)**	Arka Anamika	**105.33**	AOL-12-133	**14.997****	AOL-12-52 X GAO-5	**124.57**	AOL-12-52 X GAO-5	**19.64**	AOL-12-144 X Arka Abhay	**22.108****	**Average x Poor**
7	**Days to first picking**	JOL-69-05	**47.80**	JOL-14-10	**-2.006****	AOL-14-32 X Parbhani Kranti	**46.30**	AOL-14-32 X Parbhani Kranti	**-10.27****	AOL-12-52 X GJO-3	**-3.513****	**Poor x Poor**
8	**Days to last picking**	JOL-11-12 (104.13 days)	**104.13**	AOL-14-32	**2.377****	JOL-69-05 X Parbhani Kranti	**107.20**	JOL-69-05 X Parbhani Kranti	**6.45 ***	JOL-69-05 X Parbhani Kranti	**5.400****	**Average x Poor**
9	**Fruit length (cm)**	JOL-13.05	**12.89**	JOL-11-12	**1.243****	AOL-14-32 X Arka Anamika	**13.05**	AOL -14-32 X Arka Anamika	**11.99****	JOL-13-05 X GJO-3	**2.324****	**Poor x Poor**
10	**Fruit diameter (cm)**	Arka Abhay	**1.55**	AOL-12-59	**0.067****	JOL-69-05 X GAO-5	**1.64**	JOL-69-05 X GAO-5	**7.66**	JOL-14-10 X Arka Abhay	**0.154****	**Average x Average**
11	**Stalk length (cm)**	Prabahni Kranti	**2.71**	AOL-12-59	**-0.123****	AOL-12-59 X Parbhani Kranti	**2.63**	AOL-12-59 X Parbhani Kranti	**-14.72****	AOL-13-73 X Arka Anamika	**-0.196****	**Average x Average**
12	**Fruit weight (g)**	JOL-13-05	**16.02**	AOL-12-133	**1.000***	AOL-12-133 X Arka Abhay	**16.50**	AOL-12-133 X Arka Abhay	**16.77**	AOL-12-59 X Arka Anamika	**2.322****	**Poor x Average**
13	**Seeds per fruit**	Arka Anamika	**37.00**	AOL-12-133	**-3.392****	AOL-12-59 X GJO-3	**38.07**	AOL-12-59 X GJO-3	**-2.06**	JDNOL-11-12 X Arka Anamika	**-5.360**	**Poor x Average**
14	**100 seed weight (g)**	AOL-12-52	**3.80**	AOL-12-52	**-0.218****	AOL-12-133 X Arka Abhay	**3.94**	AOL-12-133 X Arka Abhay	**-2.47**	JOL-69-05 X GJO-3	**-0.505****	**Poor x Poor**
15	**Fruit yield per plant (g)**	GJO-3	**265.62**	JOL-14-10	**34.462****	JOL-14-10 X Arka Abhay	**310.96**	JOL-14-10 X Arka Abhay	**2.23**	JOL-13-05 X Parbhani Kranti	**63.736****	**Average x Poor**
16	**Fiber content (%)**	JDNOL-11-12	**3.90**	Arka Abhay	**-0.112***	JOL-13-05 X Parbhani Kranti	**3.78**	JOL-13-05 X Parbhani Kranti	**-25.33****	JOL-13-05 X Parbhani Kranti	**-0.846****	**Average x Average**

G: (Good) Significant in desired direction, A: (Average) Non significant but in desired direction and P: (Poor) Significant or Non-significant in undesired direction

Table.5 Best general combiner and best specific combining crosses along with their *per se* performance as well as best heterotic crosses for different traits at Achhalia

Sr. No.	Traits	Best performing parents		Good general combiners		Best cross *per se*		Most heterotic cross over check "OH-102"		Best specific crosses		
		Parent	Mean	Parent	*gca* effect					Cross	*sca* effect	Combination
1	**Days to 50% flowering**	JOL-69-05	**41.67**	AOL-14-32	**-2.364****	AOL-14-32 X GAO-5	**40.33**	AOL-14-32 X GAO-5	**-5.47**	JOL-14-10 X Parbhani Kranti	**-5.394****	**Good x Poor**
2	**First flowering node**	Arka Anamika	**3.53**	JOL-13-05	**-0.639****	JOL-13-05 X GJO-3	**3.07**	JOL-13-05 X GJO-3	**-31.34****	JOL-69-05 X Parbhani Kranti	**-1.034****	**Poor x Poor**
3	**Inter nodal length (cm)**	JDNOL-11-12	**8.20**	Arka Anamika	**-0.496****	AOL-14-32 X Arka Anamika	**7.73**	AOL-14-32 X Arka Anamika	**-15.94 ****	AOL-12-133 X Arka Abhay	**-1.330****	**Poor x Poor**
4	**Branches per plant**	JOL-69-05	**3.20**	AOL-13-73	**0.267****	AOL-14-32 X Arka Anamika	**3.33**	AOL-14-32 X Arka Anamika	**35.14 ****	AOL-14-32 X Arka Anamika	**0.661****	**Average x Poor**
5	**Fruits per plant**	GAO-5	**22.34**	JOL-14-10	**2.496****	AOL-12-52 X Arka Anamika	**24.47**	AOL-12-52 X Arka Anamika	**13.98 ****	JOL-11-12 X GAO-5	**5.155****	**Poor x Poor**
6	**plant height (cm)**	Arka Abhay	**100.27**	AOL-12-133	**13.281****	AOL-12-133 X GAO-5	**120.73**	AOL-12-133 X GAO-5	**13.90 ****	AOL-12-144 X Arka Abhay	**22.108****	**Poor x Poor**
7	**Days to first picking**	AOL-12-144	**47.00**	AOL-12-59	**-1.992****	AOL-13-73 X Arka Abhay	**46.47**	AOL-13-73 X Arka Abhay	**-4.65**	JOL-14-10 X Parbhani Kranti	**-5.189****	**Good x Poor**
8	**Days to last picking**	Arka Abhay	**105.47**	AOL-12-144	**3.422****	AOL-12-52 X Parbhani Kranti, JOL-14-10 X GJO-3	**106.93**	AOL-12-52 X Parbhani Kranti, JOL-14-10 X GJO-3	**10.77****	JOL-14-10 X GJO-3	**6.058****	**Average x Poor**
9	**Fruit length (cm)**	JOL-14-10	**15.10**	AOL-12-52	**0.921****	AOL-12-52 X GAO-5	**14.82**	AOL-12-52 X GAO-5	**15.60**	AOL-12-144 X Arka Abhay	**2.650**	**Poor x Poor**
10	**Fruit diameter (cm)**	JOL-13-05	**1.71**	Arka Anamika	**0.057****	AOL-12-144 X Arka Anamika, AOL-14-32 X Arka Abhay	**1.73**	AOL-12-144 X Arka Anamika	**13.79 ****	AOL-12-144 X Arka Anamika	**0.148****	**Average x Good**
11	**Stalk length (cm)**	AOL-12-52 and JDNOL-11-12	**2.60**	JOL-11-12	**-0.055***	JDNOL-11-12 X GJO-3	**2.65**	JDNOL-11-12 X GJO-3	**-7.66 ****	AOL-12-52 X Arka Abhay	**-0.171****	**Poor x Average**
12	**Fruit weight (g)**	JOL-13-05	**15.38**	JOL-11-12	**0.841***	AOL-12-59 X Arka Anamika	**15.54**	AOL-12-59 X Arka Anamika	**9.36**	AOL-12-59 X Arka Anamika	**2.322****	**Poor x Poor**
13	**Seeds per fruit**	GAO-5	**39.60**	JOL-14-10	**-2.824***	AOL-12-52 X GAO-5	**36.73**	AOL-12-52 X GAO-5	**-28.26****	AOL-12-133 X GAO-5	**-7.294****	**Poor x Average**
14	**100 seed weight (g)**	JOL-69-05	**4.10**	AOL-12-133	**-0.224****	JDNOL-11-12 X Arka Abhay	**4.33**	JDNOL-11-12 X Arka Abhay	**-8.19**	JOL-69-05 X GJO-3	**-0.505****	**Poor x Poor**
15	**Fruit yield per plant (g)**	Arka Anamika	**275.64**	JOL-14-10	**37.901****	JOL-14-10 X GJO-3	**335.60**	JOL-14-10 X GJO-3	**8.64**	AOL-14-32 X Parbhani Kranti	**71.498****	**Poor x Poor**
16	**Fiber content (%)**	JDNOL-11-12	**3.83**	JOL-11-12	**-0.291****	AOL-12-59 X GAO-5	**3.73**	AOL-12-59 X GAO-5	**-24.60****	AOL-12-59 X GAO-5	**-0.677****	**Good x Good**

G: (Good) Significant in desired direction, A: (Average) Non significant but in desired direction and P: (Poor) Significant or Non-significant in undesired direction

Table.6 Best general combiner and best specific combining crosses along with their *per se* performance as well as best heterotic crosses for different traits at Vyara

7.5	Traits	Best performing parents		Good general combiners		Best cross *per se*		Most heterotic cross over check "OH-102"		Best specific crosses		
		Parent	Mean	Parent	*gca* effect					Cross	*sca* effect	Combination
1	**Days to 50% flowering**	GAO-5	**43.33**	JOL-14-10	**-1.655****	AOL-13-72 X Prabhani Kranti	**43.00**	AOL-13-72 X Prabhani Kranti	**-9.15**	AOL-12-144 X GJO-3	**-5.242****	**Poor x Poor**
2	**First flowering node**	JDNOL-11-12	**2.87**	AOL-12-133	**-0.490****	JOL-14-10 X Arka Abhay	**2.73**	JOL-14-10 X Arka Abhay	**-36.93 ****	JOL-14-10 X Arka Abhay	**-1.143****	**Poor x Poor**
3	**Inter nodal length (cm)**	GJO-3	**9.60**	GJO-3	**-0.522****	AOL-12-52 X Arka Anamika, AOL-12-59 X GAO-5	**9.07**	AOL-12-52 X Arka Anamika, AOL-12-59 X GAO-5	**-4.23**	AOL-12-59 X GAO-5	**-1.490****	**Average x Poor**
4	**Branches per plant**	AOL-13-73, AOL-12-144, AOL-12-133, JOL-11-12, JOL-13-05	**2.00**	AOL-14-32	**0.301****	AOL-12-133 X GAO-5, JOL-69-05 X Parbhani Kranti	**2.60**	AOL-12-133 X GAO-5, JOL-69-05 X Parbhani Kranti	**39.29 ****	AOL-12-133 X GAO-5	**0.708****	**Poor x Average**
5	**Fruits per plant**	GAO-5	**22.34**	JOL-14-10	**1.990****	JDNOL-11-12 X GJO-3	**23.73**	JDNOL-11-12 X GJO-3	**4.71**	AOL-14-32 X Arka Anamika	**5.348****	**Poor x Good**
6	**plant height (cm)**	GJO-3	**100.93**	AOL-12-52	**9.121****	AOL-12-144 X GJO-3	**102**	AOL-12-144 X GJO-3	**10.60**	AOL-14-32 X Parbhani Kranti	**20.532****	**Poor x Good**
7	**Days to first picking**	Parbhani Kranti	**49.73**	AOL-12-59	**-1.568**	AOL-13-73 X Parbhani Kranti	**49.60**	AOL-13-73 X Parbhani Kranti	**-7.69**	AOL-12-144 X GJO-3	**-4.815****	**Poor x Poor**
8	**Days to last picking**	Arka Abhay	**104.73**	GAO-5	**1.175**	JDNOL-11-12 X GJO-3	**106.13**	JDNOL-11-12 X GJO-3	**4.46**	JOL-69-05 X Arka Abhay	**6.627****	**Poor x Poor**
9	**Fruit length (cm)**	JOL-14-10	**10.74**	AOL-14-32	**0.896****	AOL-14-32 X Parbhani Kranti	**12.67**	AOL-14-32 X Parbhani Kranti	**17.56****	AOL-12-144 X Arka Abhay	2.650**	**Poor x Poor**
10	**Fruit diameter (cm)**	AOL-14-32	**1.58**	JOL-13-05	**0.088****	JOL-14-10 X Arka Abhay	**1.72**	JOL-14-10 X Arka Abhay	**10.47**	JOL-14-10 X Arka Abhay	**0.156***	**Average x Poor**
11	**Stalk length (cm)**	AOL-12-59	**2.60**	JOL-69-05	**-0.055****	JOL-14-10 X Arka Abhay	**2.65**	JOL-14-10 X Arka Abhay	**-7.78*****	JOL-14-10 X Arka Abhay	**-0.179****	**Average x Poor**
12	**Fruit weight (g)**	JOL-13-05	**13.47**	AOL-14-32	**1.140****	AOL-14-32 X GAO-5	**13.84**	AOL-14-32 X GAO-5	**17.09**	AOL-12-59 X Arka Anamika	**2.083***	**Poor x Poor**
13	**Seeds per fruit**	Arka Anamika	**37.00**	AOL-12-133	**-2.973****	AOL-12-59 X GJO-3	**38.07**	AOL-12-59 X GJO-3	**-5.31**	JOL-11-12 X GAO-5	**-7.932****	**Poor x Poor**
14	**100 seed weight (g)**	GAO-5	**3.79**	Parbhani Kranti	**-0.135**	JOL-11-12 X GJO-3	**3.84**	JOL-11-12 X GJO-3	**-5.03**	JOL-11-12 X GJO-3	**-0.715**	**Average x Average**
15	**Fruit yield per plant (g)**	AOL-12-52	**210.75**	GJO-3	**25.414****	JOL-13-05 X GJO-3	**282.84**	JOL-13-05 X GJO-3	**3.69**	AOL-14-32 X Parbhani Kranti	**62.641****	**Average x Poor**
16	**Fiber content (%)**	Prabhani Kranti	**3.93**	AOL-13-73	**-0.214****	JOL-11-12 X Parbhani Kranti	**3.73**	JOL-11-12 X Parbhani Kranti	**-18.91****	JOL-11-12 X Parbhani Kranti	**-0.788****	**Average x Average**

G: (Good) Significant in desired direction, A: (Average) Non significant but in desired direction and P: (Poor) Significant or Non-significant in undesired direction

A summarized account of best F_1 *per se*, most heterotic crosses and best specific combinations in Table 4, 5 and 6 at Navsari, Achhalia and Vyara, respectively indicated that at Navsari hybrids *viz.,* AOL-14-32 X Arka Anamika (average x average) for internodal length, AOL-12-144 X Arka Abhay (average x average) for branches per plant, JOL-69-05 X Parbhani Kranti (Average x Poor) for days to last picking and JOL-13-05 X Parbhani Kranti (average x average) for fiber content recorded as higher *sca* effects with higher heterosis and *per se* performance. At Achhalia hybrids, AOL-14-32 X Arka Anamika (average x poor) for branches per plant, JOL-14-10 X GJO-3 (Average x Poor) for days to last picking, AOL-12-144 X Arka Anamika (average x good) for fruit diameter, AOL-12-59 X Arka Anamika (poor x poor) for fruit weight and AOL-12-59 X GAO-5 (good x good) for fiber content exhibited higher *sca* effects with highest heterosis and *per se* performance. At Vyara hybrids, JOL-14-10 X Arka Abhay (poor x poor) for first flowering node and (average x poor) for fruit diameter and stalk length, AOL-12-59 X GAO-5 (average x poor) for internodal length, AOL-12-133 X GAO-5 (poor x average) for branches per plant, JOL-11-12 X GJO-3 (average x average) for 100 seed weight and JOL-11-12 X Parbhani Kranti (average x average) for fiber content exhibited higher *sca* effects with higher heterosis and *per se* performance. Hybrid JOL-13-05 X Parbhani Kranti (average x poor) had significant desirable *sca* effect for fruit yield, fruits per plant and fiber content followed by hybrid AOL-14-32 X Parbhani Kranti exhibited poor x poor combination at Navsari. Hybrid AOL-14-32 X Parbhani Kranti (poor x poor) at Achhalia and in pooled analysis and average x poor at Vyara was reported highest *sca* effects for fruit yield, fruits per plant and also exhibited good or average *sca* effects for inter nodal length, plant height, branches per plant, fruit length, fruit weight, seeds per fruit and 100 seed weight. In general, hybrid AOL-14-32 X Parbhani Kranti reported high *sca* effects in individual as well as pooled over environment for fruit yield and also exhibited good or average *sca* effects for yield contributing traits.

Appraisal of data (Table 4, 5 and 6) at Navsari, Achhalia and Vyara, respectively revealed that the best performing parents may not be a best general combiner. Further, the best general combiner or best parent *per se* may not always produce best specific combinations for all the characters. It is further more desirable to select crosses based on *per se* performance rather than magnitude of *sca* effects; it has been earlier reported by Jethava (2014), More (2015) and Patel (2015). The hybrids showing low *sca* effects may exhibit high *per se* performance. Similar results have been reported by Singh *et al.,* (2006). Hybrid AOL-14-32 X Parbhani Kranti in individual as well as pooled over environment manifested high *sca* effects for fruit yield but the parents were poor/average general combiners. This observation corroborate with the observations of Kumar and Pathania, (2011), Singh *et al.,* (2011) and Verma *et al.,* (2016) reported in okra that the superior hybrids need not necessarily have parents showing high *gca* effects.

The hybrids exhibiting high *per se* performance for fruit yield per plant may results from good x poor combining parents at Navsari or good x good general combining parents at Achhalia and Vyara. The good general combining parents when crossed do not always produce high *sca* effects. Similarly poor general combining parents did not always produce low *sca* effects. Similar results have been reported by Pachiyappan *et al.,* (2012), More *et al.,* (2017) and Kayande *et al.,* (2018). Marked negative or non significant *sca* effects in crosses between good x good and good x average combiners could be attributed to the lack of co-adaptation between favorable alleles of the parents involved. Whereas marked positive *sca* effects in crosses between poor x poor, poor x average or average x average general combiners could be ascribed to better complementation between favorable alleles of the parents involved Patel and Mehta (1985).

Appraisal of data (Table 4, 5 and 6) revealed that for most of the traits, hybrids exhibiting higher *sca* effects for fruit yield and yield contributing traits involved poor x poor, average x poor, good x poor and average x average combiner parents, indicating the presence of both additive and non-additive gene effects for controlling fruit yield and its contributing traits. These results are in agreement with Sharma and Singh (2012), Lyngdoh *et al.,* (2017) and Annapurna and Singh (2018). Some parents with positive and significant general combining ability produced hybrids with negative and significant specific combining ability indicating the role of complementary gene action (Basak and Dana, 1971). The hybrids showed good *sca* effetcs with involved poor x poor combining parents indicating overdominance and epistatic interactions. This may be due to genetic diversity in the form of heterozygous loci as reported by Pathak and Dangaria (1987) in castor. A comparison of the hybrids selected on the basis of their *sca* effects with their mean performance at various location revealed some important features *viz.,* (1) the relative ranking of the various hybrids on the basis of *sca* effects was different at different location, (2) the ranking on the basis of *sca* effects was not always reflected by the ranking based on *per se* performance (Table 4, 5 and 6) and (3) hybrid, JOL-14-10 X Arka Abhay, JOL-14-10 X GJO-3 and JOL-13-05X GJO-3 at Navsari, Achhalia and Vyara, Respectively showing high mean performance had not always shown high *sca* effects. There was no consistent association between *per se* performance of the hybrids and their *sca* effects (Vasline and Ganesan 1995). Even with the same amount of heterotic effects, the *sca* effects may be lower where the mean performance of the parent is higher. This suggests that estimates of *sca* effects may not always lead to a correct choice of hybrid combination. These estimates may also be biased because of non-fulfillment of any of the assumption involved in the models. Hence, the choice of best hybrid combinations on the basis of *per se* performance could be more realistic and useful. Almost identical results have been reported by Patel and Mehta (1989), Vasline and Ganesan (1995), Pal and Sabesan (2009), Lyngdoh *et al.,* (2017) and Kayande *et al.,* (2018).

In conclusion the extent of possible improvement in yield is usually through screening and selecting out best adapted genotypes from the source population and utilizing them directly or through hybridization to generate high-yielding variety or hybrid. On the basis of the results obtained in the present study, it is apparent that the following points should be kept in mind before undertaking okra breeding programme. On the basis of *per se* performances, selection of parental lines are important and may be used in future breeding programme. Non-significant and desirable heterosis over standard check for fruit yield and its component traits suggested that there is no scope of exploiting heterosis commercially, but possibility of isolating desirable segregants among these hybrid combinations. Although the relative amount of *gca* and *sca* effects play a vital role in planning the most appropriate breeding programme, this objective could be fulfilled by the analysis of variance for combining ability, itself. The estimates of *gca* effects revealed that the parental lines showing high *gca* effects for fruit yield per plant used for further breeding programme. It is clear from above discussion that the high degree of non additive gene action for all the component traits observed in the present study indicated that improvement of yield and yield component traits go for bi-parental mating, recurrent selection or diallel selective mating (Jensen, 1970) than conventional pedigree or backcross breeding techniques, which would leave the unfixable components of genetic variances unexploited for yield and its components.

Acknowledgement

The authors acknowledge the support given by NAU and Deprt. of Genetics and Plant Breeding, NMCA, Navsari, Gujarat and ICAR, New Delhi for providing a Ph.D. SRF scholarship. We are also grateful to the group of vegetable scientist of Deprt. of Vegetable Science, NAU, Navsari, Gujarat, India.

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How to cite this article:

Vekariya, R. D., A. I. Patel, K. G. Modha, C. V. Kapadiya, S. C. Mali and Patel, A. A. 2020. Estimation of Heterosis, Gene Action and Combining Ability over Environments for Improvement of Fruit Yield and its Related Traits in Okra [*Abelmoschus esculentus* (L.) Moench]. *Int.J.Curr.Microbiol.App.Sci.* 9(09): 866-881.
doi: https://doi.org/10.20546/ijcmas.2020.909.109