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Genetic Analysis for Fruit Yield and its Contributing Characters in Okra (*Abelmoschus esculentus* L. Moench)

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Abstract

The components of gene effects for yield and its components in okra were studied using generation mean analysis from twelve generations (P_1, P_2, F_1, F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S}) derived from eight different genotypes. The analysis of variance between generations within family revealed that all the four crosses exhibited significant differences for days to initiation of flowering, fruit length, fruit girth, fruits per plant, fruit yield per plant, plant height, length of internode and total soluble solids brix. Mean performance of F_1 hybrids exceeded the value of their better parent in desired direction in the cross AOL 16-01 x AOL 18-08 for fruit weight, fruits per plant. In the cross GAO 5 x Red One Long for fruit length, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height, internodes on main stem. In the cross AOL 19-10 x AOL 20-03 for fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, internodes on main stem, total soluble solids. In the cross Phule Prajatika x GAO 5 for plant height, internodes on main stem, length of internode, while for days to initiation of flowering, none of the F1 per se performance was lower than its better parent. Mean performance of backcross progenies was not consistent in different crosses for different traits. The additive (d) gene effect found significant for all the four crosses for the traits viz., days to initiation of flowering, fruit length, fruits per plant and total soluble solid; crosses II, III and IV for the traits fruits per plant, fruit yield per plant and internode on main stem, crosses I, III, IV for traits fruit girth, crosses II and IV for the trait plant height, crosses III, IV for trait length of internode and cross I for the trait branches on main stem, cross III for trait fruit weight. When traits are controlled by such fixable type of gene effects, these could be improved through simple selection or a single seed descent method. Dominance (h), dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs days to initiation of flowering, fruit length, fruit girth, plant height, total soluble solid whereas dominance(h) and dominance x dominance (l) gene effect governs fruit yield per plant, dominance x dominance x dominance (z) gene effect governs fruit weight, fruit per plant, plant height, internode on main stem, length of internode. In a crop like okra, particularly dominance gene effects viz., (h) as well as (l) and (z) can be utilized in the form of hybrid variety. 10-parameter model was adequate to explain the inheritance of the traits indicating non- allelic interactions, such as first order and second order played important role to control the inheritance of most of the traits. Yield component traits in all crosses were governed by additive. dominance and digenic and/or trigenic epistasis gene effects. When additive and non-additive gene effects involved, a breeding scheme efficient in exploiting both types of gene effects should be employed. Reciprocal recurrent selection could be followed which would facilitate exploitation of both gene effects. Duplicate type of gene action would be difficult for a plant breeder to get promising segregants through conventional breeding methods, so breeding procedures involving biparental mating may be used to restore transgressive segregants.

Key words : Okra, generation mean analysis, gene action, yield.

Okra, is an important annual vegetable crop raised for its young, green, and edible fruits without fibrous skin. In several African countries, people also consume leaves in addition to fruits. Okra is now frequently found in cafeterias, salad bars, and restaurants as a fried or boiled vegetable dish. Okra stems and roots are used to purify the cane juice that is used to make gur or jaggery. Both young okra and frozen okra are in high demand right now. India is world's largest producer of okra and contributes more than

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72% (6 million tonnes) to the global production from an area of 0.5 million hectares. Okra with its significant share in fresh vegetable exports has immense potential for earning foreign exchange. According to FAO estimates around 75 percent of the okra market is in India and $_{12}$% is in Nigeria. It can be cultivated both as a rainfed and irrigated crop it is the most valued and popular vegetable consumed in fresh and dried forms. Over the last few years okra is gaining ground as a global crop because of the recognition of its nutritional values by the growing number of consumers. Especially after the COVID pandemic importance of healthy and balanced diet is getting ingrained in the global consumer mindset. India exports okra seeds to over 20 countries. In the recent past several research papers have been published by the Asian and African scientists working on okra genetics, breeding, genomics and agronomy. This further indicates okra's growing popularity as a global crop. Over 90 percent of the okra seed market in India is covered by hybrid seeds. Global seed requirement of okra is expected to touch 6000 MT mark valued at \$ 300m by 2030 (GORT 20$_{22}$).

In India okra was grown in 546 thousand hectare area with production of 6700 thousand MT and $_{12}$.27 tonnes productivity. (Anon., 20$_{21}$-$_{22}$a). The important okra growing states in India are Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Haryana and Punjab, in which it is cultivated as a Kharif as well as summer season crop. The main okra growing districts in Gujarat are Surat, Tapi, Navsari, Banaskantha, Anand, Kheda, Vadodara, Dahod, Chhota Udaipur, Bharuch, Mehsana, Gandhinagar etc. In Gujarat, it was grown in 91.177 thousand hectares area and produced of 1098.0$_{21}$ thousand MT with $_{12}$.04 MT productivity during year 20$_{21}$-$_{22}$. (Anon., 20$_{21}$-$_{22}$b). This crop is highly remunerative and generates more employment opportunities in the country. Nevertheless, the amount of vegetables produced in our country falls far short of what is needed and only provides 135 g of the daily requirement for a balanced diet per person against 300 g per day, as our population is increasing tremendously, there is an increasing demand for veggies. Vegetable crop demand is expected to reach 250 million tons by 2050. (Varmudy, 2001). High yielding and nutrient dense veggies must be produced immediately in our country to complete this titanic undertaking. Methods that offer information on the average effects of individual genes, interactions between genes of the same locus, and interactions among genes of various loci were required to determine the amount of genetic influences on the expression of quantitative traits. It is preferable to effectively exploit the available genetic variability in order to improve the yield potential. The kind and extent of genetic diversity present in the population are further clarified by genetic study of quantitative traits. The estimates of gene effects in a crop improvement program directly affect the breeding method that will be used. While dominance and epistatic effects can be employed to take advantage of hybrid vigor, additive gene effects are helpful in the production of pure lines.

Material and Methods

Data on the crop comprising twelve generations (P_1, P_2, F_1, F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S}) all grown in a year for each of the following four cross combinations, were collected and computed in this study. Four crosses *viz*., AOL 16-01 x AOL 18-08 (cross I), GAO 5 x Red One Long (cross II), AOL 19-10 x AOL 20-03 (cross III) and Phule Prajatika x GAO 5 (cross IV) and their parents were collected from Main Vegetable Research Station, Anand Agricultural University, Anand. These four crosses were produced at Main Vegetable Research Station, Anand Agricultural University, Anand during *Kharif* 2020 were utilized for making further generations to obtain seeds of F_1 (fresh), F_2, B_1 and B_2 generations during *Kharif* 20_{21}. These three generations along with parents and hybrids were grown at MVRS farm, Anand Agricultural University, Anand during summer 20_{22} to develop the subsequent generations (B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S}) and also the fresh seeds of P_1, P_2, F_1, F_2, B_1 and B_2 generations. The seeds of P_1, P_2 F_2, B_{1S} and B_{2S} were produced by selfing, while seeds of B_1, B_2, B_{11} (B_1 x P_1), B_{12} (B_1 x P_2), B_{21} (B_2 x P_1), B_{22} (B_2 x P_2) were produced by hand emasculation followed by pollination. The final evaluation of experimental materials was done during *Kharif* 20_{22}. In each replication for recording observation on eleven plant characters viz., days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height, internodes on main stem, length of internode, and total soluble solids. The analysis of variance for compact family block design was performed cross-wise for all the characters as per standard procedure (Panse *et al*. 1969). The mean values of various generations were subjected to simple scaling test A, B, C and D (Hayman *et al.* 1955) to justify the adequacy of additive dominance model. In the event of significant estimates of simple scaling test and joint scaling test, i.e. inadequacy of additive dominance model, the three-parameter model (Cavalli 1952). The joint scaling test (additive-dominance model or non-epistatic model) outlined by Cavalli (1952) was also applied to twelve generations to fit the three- parameter model m, (d) and (h). The comparison between observed and expected generation means were made by Chi-square (2) test. When three-parameter model was inadequate as indicated by significant value, digenic interactions were estimated using six-parameter model. When the six- parameter or digenic model was inadequate [2 (2) - significant], a ten-parameter model was fitted which includes second order epistatic effects.

Results and Discussion

The analysis of variance between generations within family revealed that all the four crosses exhibited significant differences for crosses exhibited significant differences for days to initiation of flowering, fruit length, fruit girth, fruits per plant, fruit yield per plant, plant height, length of internode and total soluble solids brix (Table 1). While, the generations differed significantly for fruit weight in the crosses GAO 5 x Red One Long, AOL 19-10 x AOL 20-03 and Phule Prajatika x GAO 5, for branches per plant crosses AOL 16-01 x AOL 18-08 and Phule Prajatika x GAO 5 and for internodes on main stem cross GAO 5 x Red One Long, AOL 19-10 x AOL 20-03 and Phule Prajatika x GAO 5. This indicates presence of sufficient variability in the materials under research. Considering character-cross combinations, the significant differences were observed in 40 out of 44 cases. The data for different characters were subjected to generation mean analysis only for those crosses where significant differences were observed among the generations.

Perusal of Table 2 mean performance of F_1 hybrids exceeded the value of their better parent in desired direction in the cross AOL 16-01 x AOL 18-08 for fruit weight, fruits per plant. In the cross GAO 5 x Red One Long for fruit length, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height, internodes on main stem. In the cross AOL 19-10 x AOL 20-03 for fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, internodes on main stem, total soluble solids. In the cross Phule Prajatika x GAO 5 for plant height, internodes on main stem, length of internode, while for days to initiation of flowering, none of the F_1 per se performance was lower than its better parent. Mean performance of backcross progenies was not consistent in different crosses for different traits.

Days to initiation of flowering: In cross AOL 16-01 x AOL 18-08 backcross generations B_{12} manifested lower mean value than both the parents revealing accumulation of desirable genes for earliness from corresponding parent, these generations could be further exploited for selection of permissible earliness.

Fruit length: In cross GAO 5 x Red One Long backcross generations B_1 manifested higher mean value than both the parents revealing accumulation of desirable genes for big fruit length from corresponding parent, these generations could be further exploited for selection of permissible big fruit length.

Fruit girth: In cross AOL 16-01 x AOL 18-08 backcross generations B_{22}, B_{2S}, in cross GAO 5 x Red One Long backcross generations B_1 B_2, B_{11} B_{2S}, in cross AOL 19-10 x AOL 20-03 backcross generation B_{11} manifested higher mean value than both the parents revealing accumulation of desirable genes for big fruit girth from corresponding parent, these generations could be further exploited for selection of permissible big fruit girth.

Fruit weight: In cross AOL 16-01 x AOL 18-08 backcross generations B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S}, in cross AOL 19-10 x AOL 20-03 backcross generation B_2, B_{22}, B_{2S}, in cross Phule Prajatika x GAO 5 backcross generation B_{21} manifested higher mean value than both the parents revealing accumulation of desirable genes for more fruit weight from

Table 1. Analysis of variance between families and between progenies within families of twelve generations for different characters in okra

Source of variation	df	DIF	FL	FG	FW	Fr./Pl.	FY/Pl	Br/Pl	PH	IMS	LI	TSS
Replications	2	0.01	0.01	0.001	0.58	2.38	21.05	0.06	7.15	2.25	0.10	0.004
Families	3	14.21**	0.07*	0.02**	1.03	11.38**	555.37	0.07	103.13**	11.62**	0.30**	0.471**
Error	6	0.05	0.01	0.001	0.30	1.13	148.60	0.05	8.04	1.10	0.03	0.001
Analysis of variance between generations within family												
AOL 16-01 x AOL 18-08												
Replications	2	0.13	0.16	0.009	2.47	5.28	586.53	0.17	70.49	4.19	0.18	0.06
Generations	10	7.87**	1.02**	0.40**	1.15	5.52*	653.44**	0.41**	65.82*	5.06	0.27*	1.50**
Error	21	0.28	0.32	0.003	0.92	2.37	102.16	0.12	24.48	2.35	0.11	0.005
GAO 5 x Red One Long												
Replications	2	1.04	0.0007	0.003	5.16	15.01	317.96	0.40	202.45	15.01	0.44	0.01
Generations	10	15.09**	1.81**	0.25**	9.04**	18.70**	3494.71**	0.32	399.16**	18.70**	1.23**	1.85**
Error	21	0.36	0.08	0.005	0.82	5.63	315.27	0.15	51.02	5.63	0.17	0.003
AOL 19-10 x AOL 20-03												
Replications	2	0.31	0.02	0.009	1.64	8.13	616.08	0.19	98.00	8.13	0.51	0.02
Generations	10	9.97**	1.93**	0.18**	5.43**	15.73*	5433.64**	0.29	437.19**	15.73*	1.49**	2.35**
Error	21	0.44	0.06	0.002	1.50	6.30	816.15	0.21	20.44	6.30	0.14	0.008
Phule Prajatika x GAO 5												
Replications	2	0.60	0.33	0.01	2.60	0.36	781.51	0.17	4.24	0.36	0.02	0.006
Generations	10	32.49**	0.66**	0.09**	3.61**	27.75**	1072.21*	0.49**	201.10**	27.75**	0.57**	3.44**
Error	21	0.16	0.09	0.002	0.90	6.86	457.66	0.07	13.34	6.86	0.16	0.01

*,** significant at 1 and 5 per cent levels, respectively. df: Degree of Freedom, DIF: Days to initiation of flowering, FL: Fruit length, FG: Fruit girth, FW: Fruit weight, Fr./Pl.: Fruits per plant, FY/Pl.: Fruit yield per plant, Br/Pl.: Branches per plant, PH: Plant height, IMS: Internodes on main stem, LI: Length of internode, TSS: Total soluble solids

corresponding parent, these generations could be further exploited for selection of permissible more fruit weight. The B_{22} generation exhibited the highest fruit weight than other generations in the cross AOL 16-01 x AOL 18-08 indicating accumulation of genes for this trait were originated from male parent.

Fruits per plant: In cross GAO 5 x Red One Long backcross generations B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S} in cross Phule Prajatika x GAO 5 backcross generation B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} manifested higher mean value than both the parents revealing accumulation of desirable genes for more fruits per plant from corresponding parent, these generations could be further exploited for selection of permissible more fruits per plant. Mean value of B_{22} showed the highest than all the other generations in the cross AOL 19-10 x AOL 20-03 for fruits per plant.

Fruit yield per plant: In cross AOL 16-01 x AOL 18-08 backcross generations B_1, B_{11}, B_{12}, B_{22}, B_{1S} and B_{2S}, in cross GAO 5 x Red One Long backcross generations B_{12}, B_{21}, B_{22}, B_{2S}, in cross Phule Prajatika x GAO 5 backcross generation B_{12}, B_{21}, B_{22}, B_{1S} manifested higher mean value than both the parents revealing accumulation of desirable genes for more fruit yield per plant from corresponding parent, these generations could be further exploited for selection of permissible more fruit yield per plant.

Branches per plant: In cross AOL 16-01 x AOL 18-08 backcross generations B_{1S} in cross GAO 5 x Red One Long backcross generations B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, in crosses AOL 19-10 x AOL 20-03 and Phule Prajatika x GAO 5 backcross generation B_{11}, B_{12} manifested higher mean value than both the parents revealing accumulation of desirable genes for more branches per plant from corresponding parent, these generations could be further exploited for selection of permissible more branches per plant.

Plant height: In cross AOL 16-01 x AOL 18-08 backcross generations B2, B_{12}, B_{2S}, in cross AOL 19-10 x AOL 20-03 backcross generation B_{12}, in cross Phule Prajatika x GAO 5 backcross generations B_{12}, B_{21}, B_{22}, B_{2S} manifested higher mean value than both the parents revealing accumulation of desirable genes for tallness from corresponding parent, these generations could be further exploited for selection of permissible tallness. Whereas In cross AOL 16-01 x AOL 18-08 backcross generations B1, in cross AOL 19-10 x AOL 20-03 backcross generation B_1, B_2, B_{1S}, in the cross AOL 19-10 x AOL 20-03 backcross generation B_{22} manifested lower mean value than both the parents revealing accumulation of desirable genes for dwarfness from corresponding parent, these generations could be further exploited for selection of permissible dwarfness.

Internodes on main stem: In cross AOL 19-10 x AOL 20-03 backcross generations B_1, B_2, B_{11} and Phule Prajatika x GAO 5 backcross generations B_{11}, B_{12}, B_{22}, B_{1S} manifested higher mean value than both the parents revealing accumulation of desirable genes for internodes on main stem from corresponding parent, these generations could be further exploited for selection of permissible internodes on main stem.

Length of internode: In cross AOL 16-01 x AOL 18-08 backcross generation B_2 and Phule Prajatika x GAO 5 backcross generations B_2, B_{2S} manifested higher mean value than both the parents revealing accumulation of desirable genes for length of internode from corresponding parent, these generations could be further exploited for selection of permissible length of internode.

Table 2. Per se performance of twelve generations of four crosses of okra for different characters

Cross	P_1	P_2	F_1	F_2	B_1	B_2	B_{11}	B_{12}	B_{21}	B_{22}	B_{1s}	B_{2S}	SEM	CD @5%
Days to initiation of flowering														
I	33.00±0.46	32.13±0.55	34.47±0.59	31.45±0.31	35.17±0.31	32.87±0.36	35.40±0.20	31.57±0.20	33.50±0.20	30.95±0.27	34.85±0.21	31.22±0.19	0.31	0.90
II	37.40±0.33	34.07±0.64	34.07±0.64	37.1±0.28	37.37±0.27	33.2±0.61	38.10±0.30	32.47±0.41	35.10±0.27	31.82±0.31	32.82±0.27	35.10±0.29	0.35	1.01
III	33.00±0.46	36.20±0.28	35.07±0.44	36.8±0.27	34.4±0.26	35.27±0.26	33.88±0.38	37.03±0.24	32.25±0.49	33.93±0.24	31.87±0.56	37.10±0.21	0.39	1.13
IV	25.07±0.24	33.13±0.37	29.60±0.37	31.22±0.35	28.57±0.69	32.63±0.37	25.52±0.40	30.57±0.3	29.33±0.22	35.72±0.26	26.68±0.21	32.82±0.19	0.23	0.67
Fruit length (cm)														
I	10.27±0.40	9.11±0.42	9.09±0.48	8.60±0.25	9.30±0.34	8.85±0.25	8.63±0.15	9.16±0.12	8.19±0.12	10.01±0.23	8.71±0.12	9.13±0.17	0.32	0.95
II	9.67±0.25	8.77±0.22	10.23±0.34	10.15±0.14	10.25±0.24	8.72±0.23	9.05±0.10	8.77±0.11	8.42±0.11	8.16±0.13	9.26±0.12	8.16±0.12	0.16	0.47
III	10.17±0.23	8.1±0.20	11.03±0.22	9.72±0.13	9.28±0.26	8.55±0.20	9.5±0.09	8.64±0.10	8.81±0.1	9.17±0.1	9.06±0.10	8.63±0.10	0.14	0.41
IV	10.33±0.30	9.44±0.31	9.57±0.26	9.74±0.18	9.92±0.21	9.35±0.14	9.26±0.1	8.76±0.11	8.91±0.15	8.94±0.11	9.80±0.21	9.11±0.15	0.14	0.51
Fruit girth (cm)														
I	3.56±0.10	3.13±0.07	3.31±0.03	2.79±0.03	2.80±0.04	2.91±0.04	3.11±0.03	3.40±0.03	2.77±0.03	3.57±0.03	2.62±0.03	3.69±0.03	0.03	0.10
II	2.79±0.05	3.04±0.07	2.63±0.05	2.92±0.03	3.38±0.04	3.17±0.02	3.29±0.02	2.98±0.03	2.80±0.03	2.49±0.02	3.40±0.02	3.00±0.03	0.04	0.12
III	3.16±0.08	3.02±0.05	3.31±0.04	2.77±0.02	2.74±0.03	2.56±0.03	3.41±0.02	3.0±0.03	2.90±0.02	3.10±0.03	2.93±0.03	2.85±0.03	0.02	0.07
IV	2.72±0.04	3.29±0.03	3.00±0.05	2.90±0.03	3.13±0.03	2.80±0.04	2.73±0.03	3.10±0.03	2.90±0.03	3.01±0.03	2.91±0.03	3.00±0.03	0.02	0.07
Fruit weight (g)														
I	9.71±0.55	9.59±0.18	11.06±0.44	10.13±0.33	11.63±0.42	10.70±0.29	10.43±0.31	11.15±0.25	10.37±0.21	11.28±0.14	10.71±0.10	10.8±0.28	0.55	1.62
II	7.30±0.42	11.32±0.38	9.98±0.71	9.08±0.14	8.26±0.23	8.60±0.36	6.25±0.18	9.68±0.25	11.36±0.19	10.92±0.29	8.53±0.13	11.80±0.14	0.52	1.53
III	9.24±0.27	10.75±0.16	11.01±0.65	10.96±0.08	9.20±0.22	10.22±0.16	6.32±0.21	9.73±0.08	9.38±0.12	9.90±0.22	7.86±0.22	10.04±0.23	0.71	2.08
IV	11.19±0.39	9.17±0.27	8.25±0.16	9.97±0.17	10.62±0.11	9.55±0.29	8.86±0.22	8.07±0.16	8.77±0.14	7.99±0.2	10.86±0.11	9.88±0.15	0.55	1.61
Fruits per plant														
I	20.35±0.63	17.13±0.51	15.20±0.39	18.37±0.41	17.03±0.60	17.07±0.41	19.53±0.30	19.23±0.31	17.98±0.31	18.42±0.26	18.43±0.29	18.07±0.3	0.89	2.61
II	19.0±0.82	15.47±0.41	21.0±0.70	20.3±0.28	17.33±0.57	19.67±0.45	25.35±0.39	22.92±0.52	19.32±0.33	21.08±0.5	20.48±0.58	20.32±0.31	1.37	4.02
III	19.33±0.83	23.67±0.71	26.13±1.09	22.55±0.37	21.27±0.56	23.3±0.45	20.2±0.31	21.7±0.48	21.98±0.28	27.22±0.38	24.12±0.53	21.67±0.31	1.45	4.25
IV	16.93±0.62	20.27±0.42	20.33±0.63	17.82±0.2	19.2±0.42	18.27±0.44	22.07±0.4	26.38±0.42	25.38±0.56	24.47±0.47	21.3±0.23	19.6±0.36	1.51	4.44
Fruit yield per plant (g)														
I	192.80±8.29	163.87±5.91	168.22±8.13	180.75±4.51	194.54±6.41	181.63±5.42	201.24±5.33	212.74±4.70	185.3±4.00	208.07±4.00	197.31±3.52	193.0±4.27	5.84	17.12
II	136.02±6.64	175.69±8.39	205.87±11.63	183.8±3.41	141.7±4.74	167.31±6.52	158.9±5.39	217.82±5.37	217.72±3.97	225.92±5.19	172.21±3.88	240.52±5.60	10.25	30.07
III	180.18±10.9	253.77±6.91	279.12±4.99	247.18±4.48	193.74±4.41	239.13±7.26	128.97±5.40	211.17±5.20	206.4±4.07	266.45±4.45	184.33±3.51	214.32±3.26	16.49	48.38
IV	187.89±6.28	187.11±8.20	167.38±5.29	178.13±4.15	204.3±5.58	175.12±7.29	194.28±5.19	211.59±4.46	220.99±5.05	192.39±4.26	231.46±3.65	193.29±4.54	12.35	36.23
Branches per plant														
I	2.53±0.21	1.27±0.16	1.93±0.19	2.22±0.10	2.13±0.14	2.03±0.12	2.57±0.18	2.13±0.11	2.27±0.12	2.15±0.13	2.72±0.16	2.08±0.11	0.20	0.59
II	1.93±0.18	2.27±0.24	1.73±0.19	1.92±0.10	1.67±0.15	1.87±0.14	2.55±0.13	2.53±0.17	2.38±0.12	2.43±0.13	2.35±0.13	2.48±0.11	0.22	0.65
III	2.13±0.17	2.67±0.30	2.20±0.27	2.50±.0.12	2.27±0.17	2.10±0.19	2.77±0.13	2.77±0.17	2.33±0.13	1.97±0.11	2.77±0.18	2.00±0.11	0.11	0.78
IV	1.47±0.19	2.13±0.20	1.67±0.17	1.55±0.11	1.73±0.15	1.93±0.17	2.27±0.11	2.37±0.12	1.95±0.1	2.93±0.18	2.12±0.12	2.02±0.13	0.16	0.46
Plant height (cm)														
I	110.40±1.67	118.53±1.15	106.87±0.77	114.78±1.80	109.57±1.47	122±2.60	115.35±1.46	119.78±2.00	115.03±2.47	116.28±1.42	115.22±2.48	121.37±1.44	2.86	8.38
II	124.53±1.75	140.13±2.28	143.87±3.93	120.33±2.43	108.9±2.49	118.27±3.18	127.75±2.29	144.12±2.66	129.02±3.07	136.47±2.88	118.5±2.31	139.45±3.17	4.12	12.10
III	148.07±2.84	108.13±1.92	140.07±2.95	118.72±2.29	133.3±2.68	114.43±1.49	126.93±1.98	121.75±1.65	125±2.06	108.28±2.04	124.37±1.57	117.18±1.99	2.61	7.66
IV	102.2±1.22	122.07±1.04	124.47±0.92	114.15±1.5	114.87±1.18	121.37±1.6	113.57±1.05	124.43±1.57	124.18±1.27	129.9±1.69	117.45±1.19	132.28±2.56	2.11	6.19

Table 2. *Contd...*

Cross	P_1	P_2	F_1	F_2	B_1	B_2	B_{11}	B_{12}	B_{21}	B_{22}	B_{1s}	B_{2S}	SEM	CD @5%
Internodes on main stem														
I	25.25±0.63	22.13±0.51	20.20±0.39	23.38±0.40	22.03±0.60	22.07±0.41	24.02±0.30	24.23±0.31	22.98±0.31	23.42±0.26	23.43±0.29	23.07±0.30	0.89	2.60
II	24.0±0.82	20.47±0.41	26.0±0.70	25.30±0.28	22.33±0.57	24.67±0.45	30.35±0.39	27.92±0.52	24.32±0.33	26.08±0.5	25.48±0.58	25.32±0.31	1.37	4.02
III	24.33±0.83	28.67±0.71	31.13±1.09	27.55±0.37	26.27±0.56	28.30±0.45	25.20±0.31	26.70±0.48	26.98±0.28	32.22±0.32	29.12±0.26	26.67±0.25	1.45	4.25
IV	21.93±0.62	25.27±0.42	25.33±0.63	22.82±0.2	24.20±0.42	23.27±0.44	27.07±0.4	31.38±0.42	30.38±0.56	29.47±0.47	26.30±0.23	24.60±0.36	1.51	4.44
Length of internode (cm)														
I	4.43±0.14	5.40±0.13	5.32±0.12	5.00±0.12	5.07±0.14	5.59±0.16	4.86±0.10	4.97±0.09	5.03±0.11	5.01±0.09	4.94±0.11	5.31±0.09	0.19	0.55
II	5.28±0.22	6.87±0.12	5.55±0.14	4.8±0.11	4.95±0.15	4.83±0.14	4.25±0.09	5.29±0.16	5.37±0.15	5.31±0.13	4.76±0.12	5.54±0.12	0.24	0.70
III	6.16±0.22	3.81±0.14	4.58±0.19	4.36±0.10	5.14±0.15	4.07±0.09	5.09±0.11	4.61±0.07	4.66±0.09	3.39±0.07	4.36±0.07	4.43±0.09	0.22	0.64
IV	4.70±0.13	4.85±0.08	4.95±0.13	5.02±0.07	4.79±0.09	5.26±0.11	4.24±0.07	4.02±0.08	4.16±0.08	4.48±0.09	4.49±0.06	5.43±0.12	0.23	0.67
Total soluble solids (%) Brix														
I	2.72±0.08	2.83±0.08	2.72±0.09	2.05±0.08	1.93±0.05	3.30±0.08	3.39±0.04	3.48±0.04	1.80±0.04	3.53±0.05	3.78±0.03	2.02±0.02	0.04	0.12
II	4.03±0.08	2.02±0.03	2.85±0.07	3.41±0.04	2.54±0.07	3.45±0.06	2.96±0.03	1.75±0.05	3.32±0.03	1.84±0.04	3.84±0.03	3.68±0.03	0.0	0.09
III	2.93±0.04	3.95±0.04	4.48±0.07	4.85±0.05	1.95±0.03	4.05±0.05	4.99±0.04	2.92±0.03	3.87±0.03	3.91±0.03	3.56±0.04	3.01±0.04	0.04	0.15
IV	3.91±0.04	2.67±0.05	2.24±0.06	1.88±0.03	4.76±0.08	1.82±0.06	3.51±0.04	4.69±0.06	3.84±0.03	2.79±0.03	1.76±0.06	2.91±0.03	0.06	0.17

Cross I: AOL 16-01 x AOL 18-08; Cross II: GAO 5 x Red One Long, Cross III; AOL 19-10 x AOL 20-03; Cross IV: Phule Prajatika x GAO 5

Total soluble solid: In cross AOL 16-01 x AOL 18-08 backcr$_{21}$oss generation backcross generations B_2, B_{11}, B_{12}, B_{2S} and Phule Prajatika x GAO 5 B2, B_{2S}, in cross AOL 19-10 x AOL 20-03 backcross generation B_{11} in cross Phule Prajatika x GAO 5 backcross generations B1, B_{12} manifested higher mean value than both the parents revealing accumulation of desirable genes for total soluble solid from corresponding parent, these generations could be further exploited for selection of permissible total soluble solid.

F_1 manifested higher mean value than all the other generations in the crosses AOL 16-01 x AOL 18-08, GAO 5 x Red One Long backcross and AOL 19-10 x AOL 20-03 for fruit weight, in the cross AOL 19-10 x AOL 20-03 for fruits per plant, fruits yield per plant. These generation could be further utilized for selecting higher fruit yield per plant. For selection of any traits the generation which is superior to the parents can be advanced for future breeding programme.

The significant estimate of scaling tests given by Hill indicated contribution of particular generation to non-allelic gene interactions contributed to higher order epistatic interactions.

Days to initiation of flowering: contribution to non-allelic gene interactions exhibited by B_{11}, B_{12}, B_{22}, B_{1S}, B_{2S} in crosses AOL 16-01 x AOL 18-08 and GAO 5 x Red One Long, B_{12}, B_{21}, B_{22}, B_{1S} by cross AOL 19-10 x AOL 20-03, B_{21}, B_{22}, B_{2S} by cross Phule Prajatika x GAO 5.

Fruit length: contribution to non-allelic gene interactions exhibited by B_{11}, B_{21}, B_{22}, B_{1S} in cross AOL 16-01 x AOL 18-08, by B_{11}, B_{12}, B_{21}, B_{22}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03, by B_{12}, B_{21}, B_{22}, B_{2S} in cross Phule Prajatika x GAO 5.

Fruit girth: contribution to non-allelic gene interactions exhibited by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 16-01 x AOL 18-08 by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03 by B_{22}, B_{2S} in cross Phule Prajatika x GAO 5.

Fruit weight: contribution to non-allelic gene interactions exhibited by B_{11}, B_{21}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03, by B_{11}, B_{12}, B_{22}, B_{1S}, B_{2S} in cross Phule Prajatika x GAO 5.

Fruits per plant: contribution to non-allelic gene interactions exhibited by B_{12}, B_{21}, B_{22}, B_{2S} in cross AOL 16-01 x AOL 18-08, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} in cross Phule Prajatika x GAO 5.

Fruit yield per plant: contribution to non-allelic gene interactions exhibited by B_{12}, B_{22}, B_{1S}, B_{2S} in cross AOL 16-01 x AOL 18-08 by B_{21}, B_{22}, B_{1S}, B_{2S} in cross GAO 5 x Red One Long in cross AOL 19-10 x AOL 20-03 by B_{11}, B_{12}, B_{21}, B_{1S}, B_{2S} in Phule Prajatika x GAO 5.

Branches per plant: contribution to non-allelic gene interactions exhibited by B_{12}, B_{22}, B_{1S}, B_{2S} in cross AOL 16-01 x AOL 18-08, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} in cross Phule Prajatika x GAO 5.

Plant height: contribution to non-allelic gene interactions exhibited by B_{11}, B_{12}, B_{21}, B_{2S} in cross AOL 16-01 x AOL 18-08, by B_{21}, B_{1S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} in cross AOL 19-10 x AOL 20-03, by B_{11}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross Phule Prajatika x GAO 5.

Internodes on main stem: contribution to non-allelic gene interactions exhibited by B_{11}, B_{12}, B_{22}, B_{1S}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} in cross Phule Prajatika x GAO 5.

Length of internode: contribution to non-allelic gene interactions exhibited by B_{12}, B_{22} in cross AOL 16-01 x AOL 18-08, by B_{11}, B_{12}, B_{22}, B_{1S}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{21}, B_{22}, B_{1S} in cross AOL 19-10 x AOL 20-03, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross Phule Prajatika x GAO 5.

Total soluble solid: contribution to non-allelic gene interactions exhibited by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 16-01 x AOL 18-08, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross GAO 5 x Red One Long, by B_{11}, B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross AOL 19-10 x AOL 20-03, by B_{12}, B_{21}, B_{22}, B_{1S}, B_{2S} in cross Phule Prajatika x GAO 5.

Van Der Veen's tests gives idea about presence or absence of higher epistasis, more valid conclusion can be made on the basis of $\chi^2(2)$ value at 6 degree of freedom which indicates adequacy or inadequacy of 6 parameter model and presence or absence of trigenic and higher order epistasis. The significant scaling tests of Van Der Veen and $\chi^2(2)$ together pointed out presence of trigenic or higher order epistasis in all four crosses for the characters days to initiation of flowering, fruit girth, fruits per plant, total soluble solids, in three crosses CII, III, IV characters fruit length, fruit weight, fruit yield per plant, internodes on main stem, length of internode, in crosses C I, II, IV character plant height and in cross C IV character branches per plant in all the cases Van Der Veen's tests were observed significant this indicates less influence of environment. The 3-parameter additive-dominance model was found inadequate for all four crosses for the traits viz. days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, branches on main stem, plant height, internode on main stem, length of internode and total soluble solid (brix). Surprisingly, none of the scaling tests was significant for fruits girth in the cross C IV. The 6-parameter model was also inadequate for all four crosses for all eleven characters (Table 3).

As $\chi^2(2)$ was significant so the data was subjected to 10 parameter model given by Hill for analysis of major, digenic and trigene gene effects. The additive (d) gene effect found significant for all the four crosses for the traits *viz*. days to initiation of flowering, fruit length, fruits per plant and total soluble solid, in crosses CII, III, IV for the traits viz., fruit weight, fruit yield per plant and internode on main stem; in crosses CI, III, IV for the trait fruit girth, in crosses CII, IV for the trait plant height, in crosses CI, IV for the trait length of internode and in cross CI for the trait branches on main stem. When the traits are controlled by such fixable type of gene effects, these could be improved through simple selection or a single seed descent method. Similar observations had earlier been reported by Srikanth *et al*. (2018) for fruit length, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height and internode on main stem. Liou et al. (2002) for days to initiation of flowering, fruits per plant, fruit yield per plant and plant height. Allolli *et al*. (2020) for days to initiation of flowering and fruits per plant. Gediya (2020) for days to initiation of flowering, fruit yield per plant and plant height. Deshmukh et al. (20$_{21}$) for fruit girth and fruits per plant. Whereas Nichal *et al.* (2000) reported significant estimates of additive gene effect for days to initiation of flowering, fruit girth, fruit weight, fruit yield per plant, branches per plant and plant height. Gediya (2020) for length of internode. Deshmukh *et al*. (2021) for branches per plant for both additive and dominance gene effects.

Table 3. Summary of scaling tests and gene effect for different characters in four crosses of okra

Scaling test/gene effect	Days to initiation of flowering				Fruit length			
	C I	C II	C III	C IV	C I	C II	C III	C IV
A	**	**					**	
B				**		*	**	*
C	**	**	**	**	*			
D	**	**	**			**	**	
B_{11}	**	**			**	**	**	
B_{12}	**	*	**			**	**	**
B_{21}			**	*	**	**	**	*
B_{22}	**	**	**	**	*	**		**
B_{1S}	**	**	**		**		**	
B_{2S}	**	**	**	**		**	*	**
X	**	*	**	**	*	*	**	
Y	**			*		*	**	
Three parameter model								
M								
(d)								
(h)								
$\chi^2_{(1)}$ (9 df)	**	**	**	**	**	**	**	**
Six parameter model (Hayman)								
m								
(d)								
(h)								
(i)								
(j)								
(l)								
Digenic and trigenic interactions(Hill)								
m								
(d)								
(h)								
(i)								
(j)								
(l)								
$\chi^2_{(2)}$ (6 df)	**	**	**	**	**	**	**	**
(d)	**	**	**	**	*	**		*
(h)	*	**		**	**	**	**	
(i)		**		**	**	**	**	
(j)		**	**	**				*
(l)	**	**		**	**	**	**	*
(w)	**	**	**	**	**	**		*
(x)		**	**	**	*	**	**	*
(y)		**	**	**			**	*
(z)	**	**		**	**	**	**	*
$\chi^2_{(3)}$ (2 df)	**	**		**	**	**		**
Epistasis	D	D	D	D	D	D	D	D

Scaling test/ gene effect	Fruit girth				Fruit weight			Fruits plant^{-1}			
	C I	C II	C III	C IV	C II	C III	C IV	C I	C II	C III	C IV
A	**	**	**	**		**	**		**	**	
B	**	**	**	**	**	**	**	*	**	**	**
C	**	**	**	**		**	**	**	**	**	**
D		**	**		**	**		**	**		**
B_{11}	**	**	**		**	**	**		**	*	**
B_{12}	**	**	**			**	**	**	**	**	**
B_{21}	**	**	**		**	**		**	**	**	**
B_{22}	**	**		**		**	**	**	**	**	**
B_{1S}	**	**	**			**	**		**	**	**
B_{2S}	**		**	**	**	*	**	*	**	**	
X		**	**	**	**	**	**		**	**	
Y	**	**	**	**	**	**	**	**	**	**	**
Three parameter model											
m											
(d)											
(h)											
$\chi^2_{(1)}$ (9 df)	**	**	**	**	**	**	**	**	**	**	**
Six parameter model											
m											
(d)											
(h)											
(i)											
(j)											
(l)											
Digenic and trigenic interactions(Hill)											
m											
(d)											
(h)											
(i)											
(j)											
(l)											
$\chi^2_{(2)}$ (6 df)	**	**	**	**	**	**	**	**	**	**	**
(d)	**		**	**	*				**	**	*
(h)	**	**		**	**				*	**	**
(i)	**	**	**	**	**		*			**	**
(j)	**	**	**	**	**	*			**	**	
(l)	**	**	*	**	**				**	**	**
(w)	**		**						**	**	**
(x)	**	**		**	**	**				**	**
(y)	**	**	**	**	**	**			**	**	
(z)	**	**	**	**	**			**	**	**	**
$\chi^2_{(3)}$ (2 df)	**	**	**	**	**	**	**	**	**	**	**
Epistasis	D	D	D	D	D	D	D	D	D	D	D

In cross AOL 16-01 x AOL 18-08, dominance(h), dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs days to initiation of flowering, fruit length, fruit girth, plant height, total soluble solid whereas dominance(h) and dominance x dominance (l) gene effect governs fruit yield per plant, dominance x dominance x dominance (z) gene effect governs fruit per plant. In cross GAO 5 x Red One Long dominance(h), dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs days to initiation of flowering, fruit length, fruit girth, fruit weight, fruit per plant, plant height, internode on main stem, length of internode, total soluble solid, whereas dominance(h) and dominance x dominance (l) gene effect governs fruit yield per plant. In cross AOL 19-10 x AOL 20-03 dominance(h), dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs fruit per plant, internode on main stem, length of internode, total soluble solid. In cross Phule Prajatika x GAO 5 dominance(h), dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs days to initiation of flowering, fruit girth, fruit per plant, plant height, total soluble solid, dominance(h), dominance x dominance (l) gene effect governs fruit yield per plant, branches per plant, internode on main stem, dominance x dominance (l) and dominance x dominance x dominance (z) gene effect governs fruit length. In a crop like okra, particularly dominance gene effects *viz*. (h) as well as (l) and (z) can be utilized in the form of hybrid variety.

All the three digenic interactions (i), (j) and (l) were significant for fruit girth and total soluble solid in cross AOL 16-01 x AOL 18-08, for days to initiation of flowering, fruit girth, fruit weight, plant height in cross GAO 5 x Red One Long, for fruit girth, fruits per plant, internode on main stem, length of internode, total soluble solid, in cross AOL 19-10 x AOL 20-03, for days to initiation of flowering, fruit yield per plant, plant height and total soluble solid in cross Phule Prajatika x GAO 5. All the four types of trigenic interactions *viz*, (w), (x), (y) and (z) were significant for fruit girth and total soluble solid in cross AOL 16-01 x AOL 18-08, for days to initiation of flowering, fruit yield per plant, plant height, total soluble solid in cross GAO 5 x Red One Long, for fruits per plant, fruit yield per plant, internode on main stem, length of internode, total soluble solid in cross AOL 19-10 x AOL 20-03, for days to initiation of flowering, fruit length, fruit yield per plant, total soluble solid in cross Phule Prajatika x GAO 5.

Scaling test/ gene effect	Fruit yield plant^{-1}				Branches on main stem		Plant height			
	C I	C II	C III	C IV	C I	C IV	C I	C II	C III	C IV
A		**	**	**				**	**	
B	*	*	**		**		**	**	**	
C					*		*	**	**	*
D		**	**	**				*		*
B_{11}			**	*		**	**		**	**
B_{12}	**		**	**	*	**	**		**	
B_{21}		**	**	**		*	**	*	**	**
B_{22}	**	**			**	**			**	**
B_{1S}	*	*	**	**	*	**		**	**	**
B_{2S}	**	**	**	*	**		**			**
X		**	**				*	**		*
Y			**	**		*	**			*
Three parameter model										
m										
(d)										
(h)										
χ^2 (1) (9 df)	**	**	**	**	**	**	**	**	**	**
Six parameter model										
m										
(d)										
(h)										
(i)										
(j)										
(l)										
Digenic and trigenic interactions(Hill)										
m										
(d)										
(h)										
(i)										
(j)										
(l)										
χ^2 (2) (6 df)	**	**	**	**	*	**	**	**	**	**
(d)		**	*	**	**			**		**
(h)	**	**		**		**	**	**	**	**
(i)	**	**		**		**	**	**	**	**
(j)			**	**	*			**		*
(l)	**	**		**		**	**	**	**	**
(w)		**	**	**				**		*
(x)	**	**	**	**		**	*	*	*	**
(y)		**	**	*				**		
(z)	**	*		**		**	**	*	**	**
χ^2 (3) (2 df)	**	**	**	**	**	**	**	**	**	**
Epistasis	D	D	D	D	D	D	D	D	D	D

Scaling test/ gene effect	Internode on main stem			Length of internode				Total soluble olid (brix)			
	C II	C III	C IV	C I	C II	C III	C IV	C I	C II	C III	C IV
A	**	**			**			**	**	**	**
B	**	**	**		**		**	**	**	**	**
C	**	**	**		**	**		**	**	**	**
D	**		**	*				**	**	**	**
B_{11}	**	*	**		**	**	**	**	**	**	
B_{12}	**	**	**	**	**		**	**	**	**	**
B_{21}	**	**	**			*	**	**	**	**	**
B_{22}	**	**	**	**	**	**	**	**	**	**	**
B_{1S}	**	**	**		**	**	**	**	**	*	**
B_{2S}	**	**			**		**	**	**	**	**
X	**	**				*		**	**	**	**
Y	**	**	**		**	**	**	**	**	**	**
Three parameter model											
m											
(d)											
(h)											
$\chi^2_{(1)}$ (9 df)	**	**	**	**	**	**	**	**	**	**	**
Six parameter model											
m											
(d)											
(h)											
(i)											
(j)											
(l)											
Digenic and trigenic interactions(Hill)											
m											
(d)											
(h)											
(i)											
(j)											
(l)											
$\chi^2_{(2)}$ (6 df)	**	**	**	**	**	**	**	**	**	**	**
(d)	**	**	*			**	**	**	**	**	**
(h)	*	**	**		**	**		**	**	**	**
(i)		**	**		**	**		**		**	**
(j)	**	**				**	**	**	**	**	**
(l)	**	**	**		**	**		**	**	**	**
(w)	**	**	**			**	**	**	**	**	**
(x)		**	**		*	**		**	**	**	**
(y)	**	**				**		**	**	**	**
(z)	**	**	**		**	**		**	**	**	**
$\chi^2_{(3)}$ (2 df)	**	**	**	**		**	**	**	**	**	**
Epistasis	D	D	D	D	D	D	D	D	D	D	D

*,** Significant at 5% and 1% levels respectively, C I : AOL 16-01 × AOL 18-08, C II: GAO 5 x Red One Long, C III: AOL 19-10 x AOL 20-03, C IV: Phule Prajatika x GAO 5, D: Duplicate

Interestingly, all digenic [(i), (j) and (l)] and trigenic [(w), (x), (y) and (z)] gene effects were significant for fruit girth and total soluble solid in cross AOL 16-01 x AOL 18-08, for days to initiation of flowering, fruit yield per plant, plant height in cross GAO 5 x Red One Long, for fruits per plant, internode on main stem, length of internode, total soluble solid, in cross AOL 19-10 x AOL 20-03, for days to initiation of flowering, fruit yield per plant and total soluble solid in cross Phule Prajatika x GAO 5, where additive (d) and dominance (h) gene effects and/or the digenic and trigenic epistasis collectively governed the inheritance of the trait, it would be difficult to get promising segregants through conventional breeding methods. Hence some sort of recurrent selection by ways of intermating the most desirable segregants followed by selection, diallel selective mating or the use of multiple crosses, could be effective alternative approaches for the improvement of these traits

The $\chi^2(3)$ value at 2 degree of freedom were significant in ten parameter model in cross AOL 16-01 x AOL 18-08 for days to initiation of flowering, fruit length, fruit girth, fruits per plant, fruit yield per plant, branches per plant, plant height, length of internode and total soluble solids. In cross GAO 5 x Red One Long for days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, plant height and total soluble solids. In cross AOL 19-10 x AOL 20-03 for fruit girth, fruit weight, fruits per plant, fruit yield per plant, plant height and total soluble solids. In cross Phule Prajatika x GAO 5 for days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height and total soluble solids indicating presence of higher order epistasis and/or linkage. The signs of either two or all the three gene effects *viz*., dominance (h), dominance x dominance (l) and dominance x dominance x dominance (z) suggest the presence of duplicate type of epistasis. Duplicate epistasis was observed in all the crosses for all the characters may result in decreased variation in F_2 and subsequent generations and consequently reduce heterosis and also might hinder the pace of crop improvement through selection alone. However, such characters including yield indicates that they might be improved through recurrent selection practiced in the progenies obtained through biparental mating system that in turn would help in exploiting the duplicate type of non-allelic interaction and allow recombination and concentration of genes resulting cumulative effects in population since this method is helpful in breaking up undesirable linkages as suggested for days to initiation of flowering, fruit length, fruit girth, fruits per plant, fruit yield per plant, branches per plant, plant height, internode on main stem and length of internode by Patel *et al*. (2010). Wakode et al. (2015) and Gediya (2020) reported duplicate type of epistasis for days to initiation of flowering, fruit length, fruits per plant, fruit yield per plant, branches per plant, plant height and length of internode. Akotkar *et al*. (2010) observed duplicate type of epistasis for days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, branches per plant and plant height. Adiger *et al.* (2015) reported duplicate type of epistasis for days to initiation of flowering, fruit girth, fruit weight, fruits per plant, fruit yield per plant and length of internode. Balakrishnan et al. (2014) observed duplicate type of epistasis for days to initiation of flowering, fruit weight, fruits per plant, fruit yield per plant and plant height. Akhtar *et al*. (2010) reported duplicate type of epistasis for days to initiation of flowering, fruit length, fruits per plant, fruit yield per plant and plant height. Modha (2009) observed duplicate type of epistasis for days to initiation of flowering, fruit weight, fruit yield per plant, plant height and internode on main stem. Deshmukh *et al*. (20_{21}) also reported duplicate type of epistasis for fruit length, fruit girth and fruit weight. Overall, it could be concluded that fruit yield per plant and its component traits in all four okra crosses were governed by additive, dominance and digenic and/or trigenic epistasis gene effects. When additive and non-additive gene effects involved, a breeding scheme efficient in exploiting both types of gene effects should be employed. Reciprocal recurrent selection could be followed which would facilitate exploitation of both additive and non-additive gene effects simultaneously. Under a situation of duplicate type of gene action, it would be difficult for the plant breeders to get promising segregants through conventional breeding methods. Therefore, breeding procedures involving either multiple crosses or biparental mating may be used to restore transgressive segregants.

References

Adiger, S. 2015. Genetics of yellow vein mosaic virus resistance in okra (*Abelmoschus esculenta* (L.) Moench) (Doctoral dissertation, University of Agricultural Sciences Dharwad).

Akhtar, M. Singh, J. N. Srivastav, K. and Shahi, J. P. 2010. Studies on generation mean analysis for yield and its associated traits in okra (*Abelmoschus esculentus* (L) Moench]. International Journal of Plant Sciences (Muzaffarnagar), 5(1). 323-326.

Akotkar, P. K., De, D. K. and Pal, A. K. 2010, Genetic variability and diversity in okra (*Abelmoschus esculentus* L. Moench). Electronic Journal of Plant Breeding, 1(4), 393-398.

Allolli, S., Jagtap, V. S. and Ahamed, Z. 2020. Generation mean analysis with respect of yield and percent incidence of fruit borer and yellow vain mosaic virus (YVMV) in okra (*Abelmoschus esculentus* L Moench.). Journal of Pharmacognosy and Phytochemistry, 9 (1), 2305-2308.

Anonymous. 2021-22a. National Horticulture Database. Government of India.

Anonymous. 2021-22b. Directorate of Horticulture. Government of Gujarat.

Balakrishnan, D. and Sreenivasan, E. 2014. Epistatic interactions in yield traits and fruit and shoot borer resistance. Journal of Agriculture and Environmental Sciences, 3 (2), 65-76.

Cavalli, L. L. 1952. An analysis of linkage in quantitative inheritance. In "Quantitative Inheritance". Ed. E. C. R. Reeve and C. H. Waddington, HMSO, London. Pp. 135-144.

Deshmukh, K. D., Khandare, V. S. and Jadhav S. D. 2021. Generation mean analysis in okra (*Abelmoschus esculentus* L. Moench) for yield and yield contributing characters. The Pharma Innovation Journal, 10(1): 288 -91.

Gediya. 2021. Genetics of fruit yield and its component traits in okra [*Abelmoschus esculentus* (L.) Moench.] (Doctoral dissertation, Anand Agricultural University, Anand, Gujarat).

GORT. 2022. Global okra round table, Ist Global congress, New Delhi, suvinour book. Pp. 5.

Liou, M. L., Guo, J. W. and Wu, S. T. 2002. Combining ability analysis of yield components in okra. Journal of Agriculture and Forestry, 51(2), 1-9.

Modha, K. G. 2009. Studs on heterosis and gene systems for fruit yield and its component traits in okra [*Abelmoschus esculentus* (L.) Moench] (Doctoral dissertation, AAU, Anand).

Panse, V. G. and Sukhatme, P. V. 1969. Statistical methods for agricultural workers.

Patel, K. and Savaliya, J. 2010. Generation mean analysis for fruit yield and its attributing traits in okra (*Abelmoschus esculentus* (L.) Moench]. Asian Journal of Horticulture, 5 (2), 256-259.

Srikanth, M., Dhankhar, S. K., Mamatha, N. C. and Deswal, S. 2018. Assessment of genetic architecture of some economic traits in okra (*Abelmoschus esculentus* (L.) Moench) through Generation Mean Analysis. International Journal of Current. Microbiol Applied Science, 7 (11), 2369-2379.

Varmudy, V. 2001. Marketing of vegetable in India. Daya Publishing House, New Delhi-110 035, pp. 1-15.

Wakode, M. M., Bhave, S. G., Navhale, V. C., Dalvi, V. V. and Mahadik, S. G. 2015. Genetic analysis of yield and yield contributing traits in okra (*Abelmoschus esculentus* L. Moench). Electronic Journal of Plant Breeding, 6 (4), 956-961.