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Kalyani D Deshmukh
M.Sc. Scholar, Department of Horticulture, VNMKV, Parbhani, Maharashtra, India

Vishwanath S Khandare
Research officer, Department of Horticulture Research Scheme Vegetable, VNMKV, Parbhani, Maharashtra, India

Sonam D Jadhav
M.Sc. Scholar, Department of Horticulture, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
Kalyani D Deshmukh
M.Sc. Scholar, Department of Horticulture, VNMKV, Parbhani, Maharashtra, India

Generation mean analysis in okra (*Abelmoschus esculentus* L. Moench) for yield and yield contributing characters

Kalyani D Deshmukh, Vishwanath S Khandare and Sonam D Jadhav

Abstract
The nature and magnitude of gene action was analyzed by six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) through six crosses. The results indicated that the magnitude and type of gene effects differed for the same characters in different cross combinations. The mean effect was significant and positive in all six crosses in magnitude as compared to additive and dominance effects, however the magnitude of dominance (h) gene effects was much higher than the additive (d) effects in all the crosses for majority of the traits. Among the non-allelic interactions, additive x additive (i), additive x dominance (j) and dominance x dominance (l) component were found significant. The opposite sign of domiance (h) and dominance x dominance interaction (l) showed that some characters are observed by duplicate type of epistasis and some characters are observed complementary type of epistasis.

Keywords: Okra, generation mean analysis, yield components, gene effects, epistasis

Introduction
Okra is one of the important vegetable crop grown during spring summer and rainy season. It has cultivation, export potential and high nutritive value. Okra is highly energetic of variable leading position among vegetables due to its wide adoptability and year round nutrients. It is commonly known as bhindi or lady's finger, belongs to the class dicotyledonae, order Malvales and family Malvaceae. Okra flowers are often cross-pollinated crop with somatic chromosome number 2n=130. In India, okra is trading crop grown in the states of Gujrat, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka. It is grown all over the tropical and sub-tropical regions as well as in the warmer parts of the temperate regions. The yield potential of okra is low with straight varieties (10.39t/ha) shows that there is a big difference in productivity. It is an introduced vegetable crop in India. It is extensively grown for its tender pods, which are used as a very popular, tasty and gelatinous vegetable, it is a highly energetic of valuable nutrients. It has massive socio-economic potential for enhancing livelihoods in both rural and urban areas

Materials and Methods
The experimental material in present consideration comprises six crosses PBNOK 2 x Parbhani Bhendi, PBNOK 2 x Parbhani Kranti, PBNOK 2 x Pusa Makhmali, PBNOK 4 x Parbhani Bhendi, PBNOK 6 x Pusa Makhmali, VRO 103 x Hissar Naveen along with their parental lines PBNOK-2, PBNOK-2, PBNOK-2, PBNOK-4, PBNOK-6, VRO-103, Parbhani Bhendi, Parbhani Bhendi, Parbhani Kranti, Pusa Makhmali, Pusa Makhmali, Hissar Naveen. The experiment was conducted at the Experimental Farm, Horticulture Research Scheme (Vegetable), Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The generations were analysed during *kharif* 2019 in Randomized Block Design with randomization of generations within each cross in two replications. In each replication observations were recorded on 5 random competative plant of P_1, P_2, F_1, 20 plants on F_2 and BC_1, BC_2 on 15 plants. The treatments showing significant differences for the traits were subjected to generation mean analysis and determination of gene effects using six parameter models as suggested by Hayman (1958) [5]. Chi-square test were calculated as per joint scaling test (Cavalli 1952) [4]. Presence of non-allelic gene interactions in all the crosses indicated in scaling test. Duplicate type of interaction and complementary epistasis in six crosses estimated gene effects for different traits.

Result and Discussion

Scaling test were performed as given by Hayman (1958) [5]. Scaling tests *viz.*, A, B, C, D (Table 1), showed presence of appreciable amount of epistasis in different characters. Presence of epistatic gene action for yield and its related traits have been reported earlier by Panda and Singh (2003) [10], Akthar *et al.* (2010), Mistry (2013) [9] and Soher *et al.* (2013) [13] which confirmed present results. The chi square (x^2) values were significant according to joint scaling test for first fruiting node in all six crosses studied. The significant value of chi square for this trait in all the crosses indicated that the three parameter model did not adequately explain the genetic variability for these traits. The inadequacy of the model was also indicated the presence of epistasis (non-allelic gene interaction), which was also inferred from the generation means. As the three parameter model did not satisfactorily explain the genetic variability for this trait, therefore, a six parameter model was applied to accommodate epistatic interactions. The results showed that non-allelic gene interactions of six parameter model of generation mean analysis was presented in Table 2. Estimate of gene effects from the generation mean analysis mean effect (m) was positively significant.

Fruit length (cm)

The fruit length, the Additive component (d) was negatively significant in four crosses *viz.*, PBNOK-2 x Parbhani Bhendi, PBNOK-2 x Parbhani Kranti, PBNOK-2 x Pusa Makhmali and VRO-103 x Hissar Naveen, while, the cross PBNOK-2 x Pusa Makhmali was found positively significant. The dominance (h) was positively significant in all crosses. The gene effect of additive x additive interaction (i) was positively significant in the crosses *viz.*, PBNOK-2 x Pusa Makhmali, PBNOK-4 x Parbhani Bhendi, PBNOK-6 x Pusa Makhmali and VRO-103 x Hissar Naveen. The additive x dominance interaction (j) was negatively significant in the four crosses PBNOK-2 x Parbhani Bhendi, PBNOK-2 x Pusa Makhmali, PBNOK-6 x Pusa Makhmali and VRO-103 x Hissar Naveen. Dominance x dominance interaction (1) was positively significant in four crosses *viz.*, PBNOK-2 x Parbhani Bhendi, PBNOK-2 x Parbhani Kranti, PBNOK-2 x Pusa Makhmali and PBNOK-6 x Pusa Makhmali. Whereas, the cross PBNOK-4 x Parbhani Bhendi was negatively significant interaction. Complementary type of interaction was showed to be presented in four crosses and cross PBNOK-4 x Parbhani Bhendi and VRO-103 x Hissar Naveen was observed duplicate type of interaction. The similar results are confirmed with previous researchers Salameh *et al.* (2007) [11].

Fruit girth (mm)

The fruit girth, the estimate of gene effects from the additive (d) component and additive x dominance (j) interaction positively significant in three crosses showed positive significant. Dominance (h) and additive x additive (i) component positively significant in three crosses. The dominance x dominance (l) component interaction negatively significant in four crosses. Duplicate type of interaction was observed to be presented in all crosses. Similar results were observed by Salameh *et al.* (2007) [11].

Fruit weight (g)

The fruit weight, additive (d) component negatively significant in two crosses and cross PBNOK-2 x Parbhani Bhendi, PBNOK-2 x Parbhani Kranti and PBNOK-4 x Parbhani Bhendi positively significant. The dominance (h) component positively significant in the four crosses *viz.*, PBNOK-2 x Parbhani Bhendi, PBNOK-2 x Parbhani Kranti, PBNOK-4 x Parbhani Bhendi and VRO-103 x Hissar Naveen. Additive x additive (i) interaction positively significant in the cross VRO-103 x Hissar Naveen, while, two crosses found negatively significant. The gene effect additive x dominance interaction (j) negatively significant in the four crosses. The dominance x dominance (h) component positively significant in three crosses and cross VRO-103 x Hissar Naveen negatively significant. Complementary type of interaction was observed to be presented in five crosses and cross VRO-103 x Hissar Naveen was observed duplicate type of interaction. The similar results were found by Arora *et al.* (2010) [3].

Total number of fruits per plant

Among the estimate of gene effects from the generation dominance (h) component for number of fruits per plant highly positively significant. The additive component (d) negatively significant in the cross PBNOK-6 x Pusa Makhmali and five crosses positively significant. The additive x additive (i) interaction positively significant in the three crosses. The cross VRO-103 x Hissar Naveen negatively significant. Additive x dominance (j) interaction was showed negatively significant in the cross PBNOK-6 x Pusa Makhmali. And three crosses positively significant. Dominance x dominance interaction (1) positively significant in four crosses. Complementary type of interaction was found to be presented in all crosses. The similar results were confirmed with previous findings by Kulkarni *et al.* (1998).

Table 1: Scaling test for 19 characters in 6 crosses of okra

Character and crosses	A	B	C	D
Fruit length (cm)				
PBNOK 2 X Parbhani Bhendi	-3.32** ± 0.05	-2.34** ± 0.17	-5.72** ± 0.30	-0.03 ± 0.00
PBNOK 2 X Parbhani Kranti	-1.90** ± 0.20	-1.47** ± 0.20	-3.70** ± 0.71	-0.16 ± 0.01
PBNOK 2 X Pusa Makhmali	-4.88** ± 0.01	-0.40 ± 0.24	-7.29** ± 0.25	-1.00** ± 0.01
PBNOK 4 X Parbhani Bhendi	-0.46 ± 0.12	-1.92* ± 0.80	-7.84** ± 0.99	-2.73** ± 0.01
PBNOK 6 X Pusa Makhmali	-3.01** ± 0.83	-1.12** ± 0.08	-6.53** ± 0.92	-1.20** ± 0.01
VRO 103 X Hissar Naveen	-2.13** ± 0.15	-1.17** ± 0.15	-7.10** ± 0.29	-1.90** ± 0.05
Fruit girth (mm)				
PBNOK 2 X Parbhani Bhendi	-0.44 ± 0.62	-0.63 ± 0.47	-0.80 ± 1.23	0.14 ± 0.02
PBNOK 2 X Parbhani Kranti	1.04** ± 0.02	0.39* ± 0.02	0.90** ± 0.03	-0.27** ± 0.00
PBNOK 2 X Pusa Makhmali	3.42** ± 0.14	1.16** ± 0.07	4.62** ± 0.26	0.02 ± 0.00
PBNOK 4 X Parbhani Bhendi	0.78* ± 0.10	-0.55 ± 0.31	1.37* ± 0.45	0.57** ± 0.03
PBNOK 6 X Pusa Makhmali	1.58** ± 0.19	3.04** ± 0.25	1.01 ± 0.48	-1.80** ± 0.03
VRO 103 X Hissar Naveen	1.84* ± 0.54	3.92** ± 1.31	3.48* ± 2.92	-1.14** ± 0.08
Fruit weight (g)				

PBNOK 2 X Parbhani Bhendi	-4.54** ± 0.26	-2.94** ± 0.85	-7.91** ± 1.16	-0.21 ± 0.02
PBNOK 2 X Parbhani Kranti	-4.27** ± 0.25	0.96 ± 0.52	-4.46** ± 0.44	-0.57 ± 0.16
PBNOK 2 X Pusa Makhmali	2.93** ± 0.53	1.54 ± 0.66	0.16 ± 2.05	0.77 ± 0.29
PBNOK 4 X Parbhani Bhendi	-3.50** ± 0.24	-4.91** ± 1.12	-6.30** ± 1.27	1.06** ± 0.05
PBNOK 6 X Pusa Makhmali	-3.31** ± 1.09	1.34 ± 1.52	0.09 ± 1.98	0.94* ± 0.18
VRO 103 X Hissar Naveen	-3.23** ± 0.20	2.19** ± 0.26	-7.79** ± 0.55	-3.38** ± 0.17
Total number of fruits per plant				
PBNOK 2 X Parbhani Bhendi	0.33 ± 0.14	-5.01** ± 0.21	-5.14** ± 0.52	-0.23 ± 0.12
PBNOK 2 X Parbhani Kranti	-2.47* ± 0.94	-2.73** ± 0.14	-8.24** ± 1.24	-1.52** ± 0.01
PBNOK 2 X Pusa Makhmali	-3.53** ± 0.43	-3.10** ± 0.13	-6.25** ± 0.75	0.19 ± 0.01
PBNOK 4 X Parbhani Bhendi	-2.65** ± 0.40	-4.33** ± 0.15	-13.57** ± 0.67	-3.29** ± 0.03
PBNOK 6 X Pusa Makhmali	-3.58** ± 0.05	-1.94** ± 0.46	-8.93** ± 0.27	-1.70** ± 0.10
VRO 103 X Hissar Naveen	-4.23** ± 0.09	-6.73** ± 0.00	-9.92** ± 0.22	0.52 ± 0.07

Table 2: Estimation of gene effects of 6 crosses for 19 characters in okra

Character and crosses	m	D	h	i	j	l	Type of epistasis	X^2 values
Fruit length (cm)								
PBNOK 2 X Parbhani Bhendi	10.24** ± 0.02	-0.60** ± 0.01	3.49** ± 0.29	0.06 ± 0.10	-0.49** ± 0.20	5.60** ± 0.55	Complementary	S
PBNOK 2 X Parbhani Kranti	10.64** ± 0.01	-0.41** ± 0.10	4.38** ± 0.46	0.33 ± 0.20	-0.21 ± 0.13	3.04** ± 0.93	Complementary	S
PBNOK 2 X Pusa Makhmali	9.49** ± 0.03	-1.81** ± 0.09	5.44** ± 0.33	2.01** ± 0.22	-2.24** ± 0.25	3.27** ± 0.62	Complementary	S
PBNOK 4 X Parbhani Bhendi	10.13** ± 0.01	-0.02 ± 0.10	8.06** ± 0.54	5.46** ± 0.21	0.73 ± 0.45	-3.08** ± 1.08	Duplicate	S
PBNOK 6 X Pusa Makhmali	10.20** ± 0.02	5.19** ± 0.53	8.03** ± 0.51	2.40** ± 0.23	-0.94* ± 0.46	1.73* ± 1.04	Complementary	S
VRO 103 X Hissar Naveen	9.91** ± 0.08	-1.38** ± 0.18	6.51** ± 0.52	3.80** ± 0.48	-0.48* ± 0.27	-0.50 ± 0.90	Duplicate	S
Fruit weight (g)								
PBNOK 2 X Parbhani Bhendi	11.05** ± 0.00	0.75** ± 0.14	1.89** ± 0.60	0.43 ± 0.28	-0.79 ± 0.50	7.05** ± 1.21	Complementary	S
PBNOK 2 X Parbhani Kranti	12.02** ± 0.09	0.75* ± 0.35	3.22** ± 0.85	1.15 ± 0.81	-2.62** ± 0.42	2.16 ± 1.58	Complementary	S
PBNOK 2 X Pusa Makhmali	12.36** ± 0.22	-0.18 ± 0.29	1.58 ± 1.21	-1.55 ± 1.08	-2.23** ± 0.45	2.94 ± 1.85	Complementary	S
PBNOK 4 X Parbhani Bhendi	13.30** ± 0.05	0.67** ± 0.20	4.32** ± 0.72	-2.12** ± 0.46	0.70 ± 0.57	10.54** ± 1.39	Complementary	S
PBNOK 6 X Pusa Makhmali	14.06** ± 0.03	-0.97* ± 0.42	0.91 ± 1.11	-1.88* ± 0.86	-2.33** ± 0.79	3.85* ± 2.21	Complementary	S
VRO 103 X Hissar Naveen	11.46** ± 0.15	-2.00** ± 0.28	9.25** ± 0.86	6.76** ± 0.83	-2.71** ± 0.32	-5.72** ± 1.36	Duplicate	S
Fruit girth (mm)								
PBNOK 2 X Parbhani Bhendi	12.57** ± 0.04	0.13 ± 0.10	-3.58** ± 0.10	-0.28 ± 0.28	0.09 ± 0.48	1.36 ± 1.19	Duplicate	S
PBNOK 2 X Parbhani Kranti	12.16** ± 0.00	0.33** ± 0.08	0.67** ± 0.19	0.54** ± 0.16	0.32** ± 0.11	-1.98** ± 0.38	Duplicate	S
PBNOK 2 X Pusa Makhmali	12.87** ± 0.00	0.71** ± 0.02	0.92** ± 0.26	-0.04 ± 0.05	1.13** ± 0.19	-4.54** ± 0.52	Duplicate	S
PBNOK 4 X Parbhani Bhendi	12.87** ± 0.00	0.48** ± 0.18	-0.56 ± 0.50	-1.15** ± 0.37	0.66** ± 0.24	0.92 ± 1.00	Duplicate	S
PBNOK 6 X Pusa Makhmali	11.69** ± 0.05	0.28 ± 0.14	2.80** ± 0.49	3.61** ± 0.37	-0.72** ± 0.30	-8.23** ± 0.91	Duplicate	S
VRO 103 X Hissar Naveen	11.14** ± 0.13	-0.82** ± 0.14	2.06** ± 1.00	2.28** ± 0.59	-1.03** ± 0.39	-8.04** ± 1.80	Duplicate	S
Total number of fruits per plant								
PBNOK 2 X Parbhani Bhendi	16.90** ± 0.13	1.63** ± 0.24	4.98** ± 0.75	0.46 ± 0.71	2.67** ± 0.24	4.22** ± 1.21	Complementary	S
PBNOK 2 X Parbhani Kranti	15.87** ± 0.04	0.17* ± 0.08	8.68** ± 0.59	3.04** ± 0.23	0.13 ± 0.48	2.16* ± 1.16	Complementary	S
PBNOK 2 X Pusa Makhmali	15.84** ± 0.05	2.23** ± 0.06	5.30** ± 0.49	-0.39 ± 0.25	-0.21 ± 0.31	7.03** ± 0.90	Complementary	S
PBNOK 4 X Parbhani Bhendi	14.76** ± 0.08	0.51** ± 0.06	10.93** ± 0.51	6.58** ± 0.35	0.84* ± 0.36	0.41 ± 0.85	Complementary	S
PBNOK 6 X Pusa Makhmali	15.98** ± 0.06	-0.49* ± 0.29	7.61** ± 0.67	3.41** ± 0.63	-0.82** ± 0.34	2.11 ± 1.28	Complementary	S
VRO 103 X Hissar Naveen	15.66** ± 0.11	1.46** ± 0.15	2.14** ± 0.55	-1.04* ± 0.54	1.25** ± 0.15	12.00** ± 0.77	Complementary	S

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