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Epistatic Interactions in Yield Traits and Fruit and Shoot Borer Resistance [Earias Vittella Fab.] In Okra (Abelmoschus spp.)

Dr. Divya Balakrishnan[1] and Dr. E. Sreenivasan[1]

Abstract

The gene effects for fruit yield, shoot and fruit borer resistance and its component traits in okra were studied in crosses *viz.,* Sel2 x AC 5 and KL9 x Salkeerthy. The character means of six generations were subjected to scaling test. In the presence of epistasis, six parameter model was employed to detect the gene effects. The analysis revealed the presence of duplicate non allelic interactions for most of the traits studied. Complementary epistasis govern the inheritance of fruit borer resistance in the cross Sel 2 x AC 5. These traits can be improved through bi parental mating system or recurrent parent selection. Digenic non-allelic interaction model was found inadequate to explain shoot borer infestation and it may be due to involvement of more than two genes and their interactions. The F_1 of the cross Sel 2 x AC 5 was identified as the best hybrid for both marketable fruit yield and resistance to fruit and shoot borer and it also showed field resistance to Yellow Vein Mosaic Virus.

Keywords: Okra, *Earias vitella*, generation means, yield components, gene effects

Introduction

Okra is an important vegetable crop grown throughout India for its tender pods in almost all the seasons. In case of okra, Africa is considered to be the primary centre of origin and India as one of the important centre of diversity. Okra belongs to the genus *Abelmoschus* of family *Malvaceae*. *Abelmoschus esculentus* is the major cultivated species along with a number of semi domesticated and wild species.

The cultivated species *Abelmoschus esculentus* and the semi domesticated species *Abelmoschus caillei* were used in this breeding programme.

[1] College of Horticulture, Kerala Agriculture University, Vellanikkara, 680654, Trichur, Kerala.

Among the pests of okra, shoot and fruit borer (*Earias* species) is the major pest causing high yield reduction of about 76%. Chemical usage to control the pest is not advisable as the tender pods are commonly used for consumption. Improving host plant resistance is the more economical and environmental friendly way to manage pest infestation. Information on the genetic architecture of the various traits is essential for proper selection of parents and breeding methodology. In the present investigation therefore, an attempt has been made to study the nature of gene action governing fruit and shoot borer resistance and yield attributes. Generation mean analysis is an efficient tool to understand the nature of gene action and is employed in different crops, but a very few reports are available in okra (Patel et al., 2010). Aulukha *et al.,* 2012 conducted generation mean analysis for yield parameters in okra and reported the presence of epistasis and the predominance of dominance gene effects than additive gene effects for all the traits in okra. Yield and insect resistance are complex characters results from the interaction of various attributing characters. These traits are controlled by polygene and are much influenced by environmental fluctuations (Khanorkar and Kathiria, 2010). To elucidate the nature of gene action for shoot and fruit borer resistance and yield, generation mean analysis was carried out in this study using the data recorded from two promising crosses *viz.,* Sel2 x AC5 and KL9 x Salkeerthy.

Materials and Methods

The experimental materials comprised of six varieties/lines, *viz*; Arka Anamika, KL9, Salkeerthy, Sel2, Susthira and AC5 and were crossed in a 6 x 6 complete diallel pattern. Two crosses namely, the inter-specific cross *A.esculentus* cv. Sel2 x *A. caillei* cv. AC5 and the inter varietal (*A.esculentus*) cross KL9 x Salkeerthy, as well as their six generations (P_1, P_2, F_1, F_2, BC_1 and $BC_{2)}$ were raised in RBD with four replications each. In each block single rows of parents F_1, F_2, BC_1 and BC_2s were raised with a spacing of 60x40cm. The susceptible variety Salkeerthy was grown along the borders for enhancing fruit and shoot borer infestation. Pesticides were not sprayed in the plot and the crop was left for natural infestation. All cultural operations were carried out as per the package of practice recommendations of Kerala Agricultural University 2007. The observations were recorded on parameters like days to first flowering, plant height, number of leaves per plant, number of internode on main stem, internode length, fruit number per plant, average fruit weight, fruit length, fruit girth, fruit yield per plant, marketable fruit yield, number of ridges per fruit, shoot infestation and fruit infestation.

The biometrical data obtained were subjected to generation mean analysis by six parameter model as suggested by Hayman and Mather(1955). The estimates of mean (m), additive gene effects(d) and dominant gene effects (h) were calculated through three parameter model (additive dominance model) of Jinks and Jones (1958). If epistasis was present, digenic non-allelic interaction model was resorted and six parameters *viz.*, m, d, h, i, j and l were estimated as per Hayman (1958). A joint scaling test was also carried out to test the adequacy of six parameter model.

Results and Discussion

Gene action refers to the behaviour or mode of expression of genes in a genetic population. The non allelic interaction or epistasis was absent for number of internodes, shoot infestation, fruit girth and fruit length in the cross Sel2 x AC5 (Table.1). Non additive variance was high for number of internodes, shoot infestation, fruit length and fruit girth. These traits are non fixable and selection may be ineffective, because of high dominance variance. Therefore heterosis breeding programme will be useful for improving these traits.

Generation Mean Analysis in the Cross. Sel 2 x. AC 5

Plant Height

Plant height in F_1 (89.8c.m) was much higher than both the parents, Sel2 (37.80) and AC5 (24.55). The hybrid exhibited a heterobeltiosis of 72.7 percent and inbreeding depression was 44 percent. Scaling test was significant only for ScaleB; hence epistasis was assumed to be present. For the interacting crosses, six [parameter model was adopted, the non-additive effects [h+l=135.53] were greater than additive effects [d+i=-25]. The sign of [h] and [l] are on the same direction and interaction is complementary epistasis.

Days to First Flowering

F_1 flowered earlier (39.5 days) compared to both the parents Sel2 (47.75) and AC5 (50.25 days). The F_1 manifested 27.2 percent heterobeltiosis in desirable direction (-). The estimates of scales A, B and D were significant showing presence of epistasis.

The non additive effects [h+l = -14.5] were larger than additive effects [d+i =-5.5]. Since the magnitude of [h] and [l] were on the same direction (-), there is the presence of complementary epistasis.

Number of Fruits Per Plant

F_1 hybrid recorded maximum value for this trait (10.25 no. of fruits / plant). The hybrid had shown a heterobeltiosis of 73.4 per cent and an inbreeding depression of 27.8. The estimates of scales A, B, C and D were insignificant suggesting the absence of inter allelic interaction. The additive effect was low [d =1.76] and there was a dominance effect of h= -4.46.

Fruit Weight

Fruit weight of F_1 hybrid (15.4g) was less compared to better parent Sel2 (17.28g). The heterobeltiosis was 12.6 in negative direction and with an inbreeding depression of 0.3 percent. Scales A, B and D were significant. The additive effects and additive x additive interaction effects [d+i = -8.42] were in almost equal magnitude as that of dominance, dominance x dominance effects [h+l=7.70]. Therefore, both additive and dominance effects were important for this character. The interaction was of duplicate epistasis as [h] and [l] are in opposite direction.

Fruit Yield

The F_1 hybrid recorded maximum fruit yield of 163.11, compared to parents Sel 2 (101.03) and AC 5 (36.86). The heterosis of F_1 over better parent Sel 2 was 77.4 per cent. Scaling test was significant over scale B and showed presence of epistasis. The estimates of dominance effect was high [h= -107.43] compared to the additive effects [I = 21.61]. The values of dominance and dominance x dominance interaction were in opposite direction hence the interaction was duplicate dominance.

Shoot Infestation

Shoot borer infestation in moderately resistant parent (Sel 2) was 31.92 per cent (Table 4.27), whereas in *A. caiellei* parent AC 5 shoot infestation was 2.87 per cent. Shoot borer damage in the F_1 was 12.78 per cent. The mean shoot infestation in the segregating generation *i.e.* F_2, B_1 and B_2 were within the range of parents.

Shoot borer infestation shown a heterobeltiosis of 77.5 percent over better parent and with an inbreeding depression of 15.4 per cent in negative direction. Scaling test was not significant suggesting inter allelic interaction. The additive effect was negative [d= -13.53] whereas the dominance effect was positive [h=26.97].

Fruit Infestation

Fruit borer infestation among six generation materials varied from 4.25 to 26.8 per cent. The F_1 manifested 78.62 per cent heterobeltiosis in desirable direction (-). Infestation in the F_2 and backcross progenies (B_1 and B_2) falls within their parental values *i.e.* 24.13 to 17.83 per cent. The genes interact as evident from the significance of scales A and B. The non additive effects [h+l=-47.84] were larger than additive effects [d+i=14.71]. The sign of [h] and [l] were in the same direction (+) and hence the interaction is complementary epistasis.

Generation Mean Analysis in the Cross KL 9 x Salkeerthy

Plant Height

The F_1 manifested 3.9 percent heterosis over better parent in negative direction. But the F_2 segregants (mean = 45.17cm) having more plant height than F_1s (945.29) but further reduction in height was noticed in the back cross progenies (934.43 to 37.49). The scale B was significant, hence the epistasis assumed to be present. The duplicate digenic non allelic interaction model is found to be adequate to explain the gene action.

Days to First Flowering

Salkeerthy flowered earlier (38.25days) than KL 9 (40.25). The F_1 flowered earliest i.e. 34.75 days, but the derivatives from these parents i.e.

F_2, BC_1 and BC_2 have flowered later than both the parents (38.75, 41 and 44.33 respectively). The hybrid manifested heterobeltiosis of 10.1 per cent in desirable direction (-) for this trait. Scales A and B were significant epistasis is present. Both additive (d = -3.33) and additive x additive effects (I =15.67) were significant.

Number of Fruits Per Plant

The F_1 hybrids showed more number of fruits (10.26) than both the parents and F_2 had an average of 11.3. Heterobeltiosis was 2.5 percent and with an inbreeding depression of -10.1 per cent. Scaling test indicated presence of inter allelic interaction with significance on scales A and B. The joint scaling test indicated the presence of duplicate epistasis.

Fruit Weight

Fruit weight ranged between 17.91 to 20.56 g. Next to F_1 (19.38) fruit weight was high in F_2 (18.6) and it was reduced in back crosses. Scales A and D were significant indicating the presence of epistasis. The additive effects and additive x additive interaction effects [d+i =- 4.54] were lesser than the dominance and dominance x dominance effects [h+l = 7.66]

Fruit Yield

The F_1 manifested a fruit yield of 197.58 g and was intermediate between both the parents KL9 (174.2) and Salkeerthy (205.04). But F_2 showed a higher yield compared to F_1 i.e. 209.57 g. The heterosis was 3.8 percent in negative direction. Scale A was significant. The estimates of [h] and [l] showed opposite sign hence it was duplicate epistasis.

Shoot Infestation

Shoot infestation in parent KL 9 was 29.68 and in Salkeerthy it was 27.01. The hybrid showed 15.86 per cent of shoot damage with high heterobeltiosis of 70.3 in the desirable direction (-). The estimates of scales A, B, C and D were insignificant suggesting the absence of inter allelic interaction. The additive effect was 8.72 and the dominance effect was -20.37.

Fruit Infestation

Fruit borer infestation was low in F_1 hybrid *i.e.* 22.37 compared to all other five generations where infestation ranged from 33.64 to 26.58 per cent. Scales A and B were significant, thereby suggesting the presence of interallelic interaction of all kinds. Additive effects [d = -4.93] were low and negative, while additive x additive interaction effects were high and positive [i = 18.37].

Similarly dominance effects [h = 13.27] and dominance x dominance interaction effect were positive [l = -43.88]. Thus the interaction was of duplicate epistasis.

Epistasis was observed for plant height, days to first flowering, leaf number, internodal length, fruit infestation, flowering period, marketable fruit yield, fruit weight and fruit yield. The digenic non-allelic interaction model was found adequate to explain the gene action in these traits. The interaction was complementary for plant height, days to first flowering, leaf number, fruit infestation but duplicate epistasis was observed for internodal length, flowering period, fruit weight and fruit yield. In duplicate epistasis, due to negative dominance in some locus, mutual cancellation of positive and negative effects may take place. In such situation additive effects would be important in deciding the net effects. Hence Karuppaiyan, (2006) reported that heterosis breeding is not desirable is case of duplicate epitasis but it would be possible to isolate segregants as good as that of F_1 in the subsequent filial generations. More reliance should be placed on selection between families and lines for the traits with relatively high epistatic variance.

Scaling test was done to detect the presence of epistasis given in the Table.5 and Table.6. Inter allelic interaction (epistasis) was present for most of the traits except number of internodes, internodal length, number of ridges, shoot infestation and fruit length in KL 9 x Salkeerthy (Table.3). Non Additive variance was high for internode number, number of ridges, shoot infestation, fruit length but additive variance was high for internodal length. The breeding objective should be towards development of hybrids for commercial purpose in case of the traits with high dominance variance. Selection is the reliable breeding method for improving varieties for the characters with high additive variance. When non additive gene effects are greater than additive gene effects biparental mating or recurrent selection can be done to get more heritable variation for simultaneous improvement of fruit yield and its components.

The dominance (h), additive x additive (i) and dominance x dominance (l) gene effects were important for most of the traits in two crosses under generation mean analysis (Table.2 and 4).

Duplicate epistasis was observed for plant height, days to first flowering, leaf number, fruit number, fruit infestation, flowering period, fruit weight and fruit yield. Hence it would be desirable to go for recombination breeding to isolate useful segregants. The duplicate dominant epistasis in the inheritance of the characters studied was earlier reported by Arumugam and Muthukrishnan (1979), Korla and Sharma (1987) and Panda and Singh (2005) in okra. In case of fruit girth complementary digenic non-allelic model was found adequate and these are fixable and can be exploited effectively for the improvement of traits by pedigree method of selection. Arora *et al.,* 2010 observed that the additive, dominance and digenic non-allelic gene interactions were observed to govern most of the fruit traits. Reddy *et al.,* 2012 explained similar results like non-additive gene action is observed for plant height, internodal length, days to 50% flowering, first flowering and fruiting node, fruit length and weight, total number of fruits and number of marketable fruits per plant, total yield and additive gene action for number of branches per plant and fruit and shoot borer infestation. Khanorkar and Kathiria, 2010 suggested that the results on epistatic gene effects for fruit yield and related traits in multiple environments requires recurrent selection, bi-parental mating and inter se mating between desirable segregants followed by selection or multiple crosses offer good promising methods to develop high yielding varieties.

This study indicated that generation mean analysis of Sel2 x AC5 indicated the presence of complementary epistasis for plant height and fruit infestation and duplicate epistasis for fruit number, fruit weight and fruit yield. In the inter varietal cross KL9 x Salkeerthy it was observed that duplicate epistasis govern the fruit borer resistance, fruit weight, fruit yield and days to first flowering. Digenic non-allelic interaction model was inadequate to explain shoot borer infestation. The F_1 of the cross Sel 2 x AC 5 was identified as the best hybrid for both marketable fruit yield and resistance to fruit and shoot borer and it also showed field resistance to Yellow Vein Mosaic Virus. This study may help in development of lines with higher levels of resistance. The wild genotypes from *Abelmoshus caillei* identified in this study will be an excellent donor material to further enhance host plant resistance of okra against many biotic stresses.

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Table 1: **Mean Performance of Six Generation Materials of Inter Specific Cross Sel2 X AC 5 for Various Quantitative Traits**

	Pht	Dff	L.no.	IN	IL	FN	Nr	SI	FI	Flp	MFY	FG	FW	FY	FL
P1	37.8	47.75	20.12	9.14	6.03	5.88	5	31.92	26.8	28.16	74.43	7.55	17.28	101.03	22
P2	24.55	50.25	26.02	8.49	5.06	2.73	5	2.87	19.88	31.98	29.24	8.13	13.54	36.86	15.45
F1	89.8	39.5	30.14	13.37	6.19	10.25	5	12.78	4.25	29.23	152.41	7.13	15.49	163.11	20.5
F2	50.29	45	21.97	10.15	5.9	7.4	5	14.75	18.88	29.87	98.84	7.05	15.54	115.58	21.13
BC1	46.82	41.75	22.67	10.42	5.62	5.67	5	15.88	24.13	29.59	56.95	6.63	13.33	75.98	21.75
BC2	35.71	49.25	21.35	9.66	5.77	3.92	5	29.4	17.83	29.42	45.12	7.38	13.77	54.37	21
di	0.727	-0.272	0.137	0.365	0.183	0.734	0.000	0.775	-3.678	-0.094	0.808	-0.140	0.126	0.774	0.246
ID	0.440	-0.139	0.271	0.241	0.047	0.278	0.000	-0.154	-3.442	-0.022	0.351	0.011	-0.003	0.291	-0.031

di- heterobeltiosis –(F1- BP) / F1, ID- Inbreeding Depression – (F1- F2) / F1

Table.2: **Estimates of Gene Effects Based on Six Generation Means**

	Pht	Dff	L.no.	IN	IL	FN	Nr	SI	FI	Flp	MFY	FG	FW	FY	FL
m	40.86	43.50	22.23	9.88	5.78	5.01	5.00	17.27	20.20	30.50	54.38	6.88	13.62	68.13	21.75
d	11.12	-7.50	1.31	0.76	-0.15	1.76	0.00	-13.53	6.30	0.17	11.83	-0.75	-0.44	21.61	0.75
h	22.52	-7.50	7.22	4.11	-0.16	-4.46	0.00	26.97	-10.68	-2.31	-90.67	-0.91	-7.89	-107.43	2.78
i	-36.12	2.00	0.15	-0.45	-0.81	-10.41	0.00	31.58	8.41	-1.47	-191.24	-0.20	-7.98	-201.60	1.00
j	4.50	-6.25	4.26	0.43	-0.63	0.19	0.00	-28.05	2.83	2.08	-10.77	-0.46	-2.31	-10.48	-2.53
l	113.01	-7.00	18.24	4.66	1.49	20.34	0.00	-61.80	-37.16	2.06	395.61	2.13	15.59	405.00	-8.05

Dff-Days to first flowering, Pht-Plant height (cm), LNo-Number of leaves/plant, IN-Number of internode on main stem, IL-Internode length, FN-Fruit number / plant, FW-Average fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, MFY- Marketable fruit yield (g), Nr – No. of ridges per fruit, SI – Shoot infestation (%), FI – Fruit infestation (%) Flp – flowering period (days)

Table.3: Mean Performance of six Generation Materials of inter Specific Cross KL9X Salkeerthy for Various Quantitative Traits

	Pht	Dff	L.no.	IN	IL	FN	Nr	SI	FI	Flp	MFY	FG	FW	FY	FL
P1	39.02	40.25	22.58	7.61	4.22	8.78	5.75	29.68	27.93	26.63	124.07	6.88	19.39	174.2	21.63
P2	44.27	38.25	23.64	7.95	4.29	10	8	27.01	27.02	28.94	156	8	20.56	205.04	17.38
F1	42.59	34.75	21.46	8.42	4.19	10.26	7	15.86	22.37	30.42	157.03	7.93	19.38	197.58	19.13
F2	45.17	38.75	19.67	8.21	3.96	11.3	7.25	26.03	26.58	25.78	150.72	7.5	18.6	209.57	18.88
BC1	37.49	41	17.5	7.35	4.29	6.29	8	28.42	28.71	28.45	77.33	7.5	17.32	108.81	19.5
BC2	34.43	44.33	16.58	7.19	3.33	6.75	8.67	19.7	33.64	29.68	82.35	7.5	17.91	120.92	17
di	-0.039	-0.101	-0.102	0.056	-0.024	0.025	-0.143	-0.703	-0.208	0.049	0.007	-0.009	-0.061	-0.038	0.091
ID	-0.061	-0.115	0.083	0.025	0.055	-0.101	-0.036	-0.641	-0.188	0.153	0.040	0.054	0.040	-0.061	0.013

di- heterobeltiosis –(F1- BP) / F1, ID- Inbreeding Depression – (F1- F2) / F1

Table.4: Estimates of Gene Effects Based on Six Generation Means

	Pht	Dff	L.no.	IN	IL	FN	Nr	SI	FI	Flp	MFY	FG	FW	FY	FL
m	35.57	41.25	16.06	7.08	4.46	5.92	8.00	24.44	33.16	27.40	70.87	7.75	17.76	104.36	19.00
d	3.05	-3.33	0.91	0.16	0.96	-0.46	-0.67	8.72	-4.93	-1.23	-5.01	0.00	-0.59	-12.11	2.50
h	-35.90	11.17	-12.15	-3.12	-0.64	-18.24	4.46	-20.37	13.27	15.77	-266.53	0.49	-4.55	-370.86	-2.88
i	-36.84	15.67	-10.50	-3.76	-0.58	-19.11	4.33	-7.89	18.37	13.13	-283.53	0.00	-3.95	-378.83	-2.50
j	5.68	-4.33	1.44	0.34	1.00	0.15	0.46	7.39	-5.38	-0.08	10.95	0.56	-0.01	3.31	0.38
l	61.48	-38.33	31.48	7.07	2.23	32.33	-9.92	0.07	-43.38	-12.97	558.29	0.73	12.21	693.77	6.75

Dff-Days to first flowering, Pht-Plant height (cm), LNo-Number of leaves/plant, IN-Number of internode on main stem, IL-Internode length, FN-Fruit number / plant, FW-Average fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, MFY- Marketable fruit yeield (g), Nr – No. of ridges per fruit, SI – Shoot infestation (%), FI – Fruit infestation (%) Flp – flowering period (days)

Table.5: Scaling test to detect the Presence Epistasis in the cross Sel2 x AC 5 for Various Quantitative Traits

Traits	Scale A	Scale B	Scale C	Scale D	χ^2
Plant height	0.02	-2.77*	-0.97	0.34	50.80
Days to first flowering	2.69*	10.95*	0.85	6.57*	94.02
Leaf no.	1.10	-2.25*	-2.82*	0.96	21.27
No. Of internodes	0.77	1.94	1.02	0.45	10.71
Internodal length	1.18	2.58*	0.52	0.81	33.97
No. Of fruits	1.14	-0.11	0.90	0.01	44.28
No. Of ridges	1.29	2.04*	33.06*	1.31	23.21
shoot infestation	0.30	0.55	0.69	0.58	15.45
fruit infestation	-2.11*	-3.22*	-0.98	1.28	84.92
fruit girth	0.69	0.42	0.42	0.95	60.33
Fruit weight	2.25*	5.59*	1.76	4.32*	23.06
Fruit yield	-1.66	-3.17*	-0.67	1.02	48.37
Fruit length	0.83	1.24	0.66	0.70	33.14

Table.6: **Scaling Test to Detect the Presence Epistasis in the Cross KL9 x Salkeerthy for Various Quantitative Traits**

Traits	Scale A	Scale B	Scale C	Scale D	χ^2
Plant height	-1.62	-2.53*	-1.88	1.29	30.81
Days to first flowering	3.64*	6.09*	1.28	1.02	37.29
Leaf no.	1.08	-3.87*	-2.51*	0.03	3.88
No. Of internodes	0.44	0.72	0.38	0.06	50.42
Internodal length	1.58	1.81	0.04	1.05	1.28
No. Of fruits	-2.57*	2.52*	-0.21	-1.74	.73
No. Of ridges	1.54	1.35	0.62	-0.26	8.87
shoot infestation	0.64	0.32	0.50	0.38	62.44
fruit infestation	-2.57*	-2.12*	-0.08	1.26	5.18
fruit girth	1.44	0.54	66.00*	0.08	46.7
Fruit weight	3.73*	1.13	0.13	2.57*	12.54
Fruit yield	-2.09*	-1.78	0.01	1.29	26.81
Fruit length	0.28	1.30	1.38	0.18	23.17