Plant Archives Vol. 16 No. 2, 2016 pp. 669-674 ***ISSN 0972-5210***

STUDIES ON HETEROSIS, INBREEDING DEPRESSION AND RESIDUAL HETEROSIS FOR FRUIT YIELD AND ITS COMPONENTS IN OKRA [*ABELMOSCHUS ESCULENTUS* (L.) MOENCH]

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Abstract

An experiment was conducted to study the presence of heterosis, inbreeding depression and the extent of residual heterosis in three cross combinations of okra namely, Arka Anamika × Parbhani Kranti, Arka Anamika × MDU 1 and Parbhani Kranti × MDU 1 involving five generations *viz*., P_1, P_2, F_1, F_2 and F_3. The extent of relative heterosis, heterobeltiosis and standard heterosis was estimated for assessing the hybrid value for nine quantitative characters *viz*., days to first flower, plant height, inter node length, number of nodes per plant, number of fruits per plant, fruit length, fruit girth, fruit weight and fruit yield per plant. The cross Arka Anamika × Parbhani Kranti showed favorable significant relative heterosis and standard heterosis for days to first flower, plant height, number of fruits per plant, fruit length, fruit weight and fruit yield per plant. The same cross also recorded high residual heterosis for days to first flower, plant height, fruit weight and fruit yield per plant along with low inbreeding depression for these traits. Presence of hybrid vigour for fruit yield per plant in F_2 and F_3 generations may be attributed to additive and additive × additive gene interaction and such cross was expected to give superior segregants, which may be handled through pedigree breeding method. Inbreeding depression was high in good performing hybrids. High yielding F_1 hybrids performed poor in the subsequent generation due to inbreeding depression, while moderate yielding F_1 hybrids were found more stable even passing through process of segregation. It is also suggested that combined performance of F_1 and F_2 hybrids could be a good indicator to identify the most promising populations to be utilized either as F_2 hybrids or as a resource population for further selection in advanced generations.

Key words : Bhindi, hybrid vigour, F_2 and F_3 generation, pod yield.

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] belonging to the family Malvaceae is an important vegetable crop in India. The major problem in okra cultivation is lack of high yielding varieties along with location specific pest and disease tolerant hybrids. Of the various approaches to overcome this problem, exploitation of heterosis is considered as one of the desirable and sustainable approach. Heterosis has been exploited for increasing the yield in several crops. The knowledge of heterosis helps in identifying best combiners, either to exploit heterosis or to accumulate fixable genes through selection. The heterosis reveals the type of gene action involved and it helps in the selection of suitable breeding methodology and parameters, which are employed for crop improvement programme. However, direct use of heterosis in okra is limited. From economic point of view retention of heterosis in further generations is more practical, which implies that the degree of inbreeding depression should be low.

Inbreeding reduces the mean phenotypic value of various fitness-related traits and the phenomenon is known as inbreeding depression (Stebbins, 1958; Wright, 1977). Heterosis resulting from crosses between strains or between different races or varieties is theoretically known as the reverse of inbreeding depression, and forms an important means of genetic improvements (Falconer, 1989). In general, inbreeding depression and heterosis are associated with changes in heterozygosity and homozygosity for several reasons (Falconer, 1989). First, homozygotes may have reduced fitness value for traits which are controlled by directionally dominant alleles and second, increasing homozygosity increases the chances of the expression of deleterious recessive alleles. The relationship between the amount of inbreeding depression

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and heterosis as defined in the present study is in accordance with the theory that the phenomenon of heterosis is the reverse of inbreeding depression (Falconer, 1989), indicating that the traits, which have decreased by inbreeding can be recovered by crossing.

Bhendi, being a self pollinated crop, the scope for exploitation of hybrid vigour depends on the magnitude of heterosis, biological feasibility and the types of gene action involved. From economic point of view, retention of heterosis in F_2 and later generations is more practical importance. Low inbreeding depression might be the reason for residual heterosis (Kumar, 1998). The present study examines the effects of inbreeding and crossing on various quantitative traits and the relationship between the amount of inbreeding depression and heterosis for these traits in okra.

Materials and Methods

The experimental material comprised of three parents namely, Arka Anamika (AA), Parbhani Kranti (PK) and MDU 1 were crossed to produce three hybrids during July, 2006. The hybrids namely, Arka Anamika × Parbhani Kranti (AA × PK), Arka Anamika × MDU 1 (AA × MDU 1) and Parbhani Kranti × MDU 1 (PK × MDU 1) were raised during January, 2007 to get F_2 seeds. They were forwarded to F_3 generation during July, 2007. The parents, F_1s, F_2s and F_3s were evaluated during January, 2008 in a randomized block design with three replications at the Plant Breeding Farm (11° 24' N latitude and 79° 44' E longitude, + 5.79 m MSL), Annamalai University, Annamalainagar, Tamilnadu, South India. In each replication, each entry was grown in five rows having 30 plants with 45 cm and 30 cm inter row and inter row spacing, respectively. The experiment was conducted with normal package of practices and need based plant protection measures. The observations were recorded on ten randomly selected plants from each genotype in each replication for P_1, P_2 and F_1 generation. For segregating generations (F_2 and F_3) observations were recorded for seventy plants per replication.

The mean of F_1 hybrids over replication were utilized for the estimation of heterosis. The magnitude to heterosis was calculated and presented as per Turner (1953) and Hayes *et al*. (1956). The residual heterosis and inbreeding depression was worked out in F_2 and F_3 generation as per the formula given below:

$$\text{Residual heterosis in } F_2 = \text{di} = \frac{\overline{F}_2 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Residual heterosis in } F_3 = \text{di} = \frac{\overline{F}_3 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Inbreeding depression in } F_2 \ \text{di} = \frac{\overline{F}_1 - \overline{F}_2}{\overline{F}_1} \times 100$$

$$\text{Inbreeding depression in } F_3 \ \text{di} = \frac{\overline{F}_1 - \overline{F}_3}{\overline{F}_1} \times 100$$

Where,

F_1 = mean of the F_1 generation, F_2 = mean of the F_2 generation, F_3 = mean of the F_3 generation, MP = Midparent mean

The significance was tested using the formulae suggested by Wynne *et al*. (1970).

Results and Discussion

Mean performance

The mean performance of F_1 hybrids, F_2, F_3 populations and their parents are furnished in table 1. The mean squares from the analysis of variance showed significant difference for all the traits under investigation. For the mean performance, all the three hybrids showed earliness in flowering, tallness, set more fruits per plant with long fruits and more weight than their respective parents whereas, majority but not all the F2s were superior to their respective parents for these traits. These results are in conformity with the earlier reports of Surendrakumar *et al*. (2004) and Nandan Mehta *et al*. (2007). The F_2 mean was lower than their corresponding F1 mean in all the crosses for almost all the traits except days to first flower and plant height. The F_3 mean was higher than the F_2 mean in the cross AA × PK for days to first flower, plant height, internodal length, number of fruits per plant, fruit girth and fruit weight. In general the mean performance of the hybrid AA × MDU 1 was high for all the key traits studied except for earliness and fruit weight followed by the hybrid AA × PK, which recorded earliness for flowering, long internodes and plant height.

Heterosis, residual heterosis and inbreeding depression

The data on heterosis in the F_1 and the percentage of relative heterosis and inbreeding depression in F_2 and F_3 generation for all the nine traits are furnished in table 2 and discussed hereunder.

Days to first flower

The crosses AA × PK and PK × MDU 1 recorded significant heterosis in the desirable direction for all the three types of heterosis. The cross AA × MDU 1 recorded favourable standard heterosis of -4.61%. High heterosis for days to first flower was also reported by Rewale *et al*. (2003) and Weerasekara *et al*. (2008). The same trend was observed for residual heterosis in the F_2 and F_3 generations. Inbreeding depression was found to be very low for this trait which ranged from -0.15 to -4.55% in F_2 and from -0.33 to 0.87% in F_3 generation. The presence of heterosis in the F_1 and residual heterosis in F_2 and F_3 generations along with non-significant inbreeding depression indicates the role of additive gene action. The results are in agreement with the findings of El-Gazar *et al*. (1988).

Plant height

The cross AA×PK alone recorded positively significant relative and standard heterosis for plant height which ranged from -8.78 to 8.19% and from 1.71 to 14.75%, respectively. Pathak and Syamal (1997), Ahmad *et al*. (1999) and Rewale *et al*. (2003) and reported high heterotic value for this trait. Positively significant residual heterosis in both F_2 and F_3 generations was recorded by the same cross. The inbreeding depression ranged from -1.93 to -20.40% in F_2 and from -1.97 to -9.43% in F_3 generation respectively. The cross PK×MDU1 which registered significant inbreeding depression in the F_2 generation recorded low heterotic values in F_1 generation while significant residual heterosis value was noted for this cross in F_2. This might be due to fixation of genes in the early generation (Natarajan and Gunasekaran, 2008).

Internodal length

For intermodal length, the crosses AA×PK and PK×MDU1 recorded significant heterosis in all the three bases of heterosis. Mid parental heterosis ranged from 15, 45 to 36.16%. High heterosis for intermodal length was earlier reported by Saravanan (2001). Significant inbreeding depression (10.94%) was recorded in F_2 generation in the cross PK × MDU1 while in F3 generation both AA × PK and PK × MDU1 recorded significant inbreeding depression values. The presence of high heterosis along with inbreeding depression indicates that this trait is influenced by non additive gene action which corroborated with the non-significant residual heterosis in the F_2 and F_3 generation in all the three crosses.

Number of nodes per plant

In F_1 generation, the two crosses namely AA×MDU1 and PK × MDU1 recorded positively significant heterobeltiosis, relative and standard heterosis for this trait. Standard heterosis for this trait varied from 26.72 to 60.78%. Significant residual heterosis in both F_2 and F_3 generation was also recorded by these crosses. Inbreeding depression observed for these crosses also showed the same trend for this trait in both the segregating generations. Our results, that high heterosis was generally associated with high inbreeding depression wherein conformity with those of Wang and Pan (1991) and Saravanan (2001).

Number of fruits per plant

For number of fruits per plant the maximum significant standard heterosis of 156.72 was recorded by the cross AA×PK for which the values ranged from 30.30 to 156.72%. High heterosis for this trait was also reported by Rewale *et al*. (2003) and Weerasekara *et al*. (2008). High inbreeding depression was observed in F_2 (42.30%) and F_3 (41.15%) generations. Residual heterosis was negatively significant in the cross AA×PK, while it was non-significant in other crosses. Negative heterosis in F_2 population indicated that these traits suffer severe inbreeding depression. The presence of high heterosis along with inbreeding depression indicates that this trait is influenced by non additive gene action. Hence, selection in early generations is not suggested and breeder has to wait till later generations when genes get established through crossover phenomenon. Similar result was observed by More and Patil (1997) for this trait.

Fruit length

The better parent heterosis values ranged from 3,60% to 71.72% while the standard heterosis varied from 18.74 to 96.82%. Excepting non significant heterobeltiosis recorded by the cross AA×PK all other values were positively significant in all the three crosses. Similar results were reported by Mehta (2007) and Bhoovaragamoorthy (2008). All the F_2 genotypes displayed significant inbreeding depression for fruit length and the observed inbreeding depression was between 5.50 to 41.31% and 6.81 to 45.17% in F_2 and F_3 generations, respectively. Residual heterosis was non significant in both the segregating generations. The presence of significant heterosis in F_1s and inbreeding depression in segregating populations coupled with non significant residual heterosis indicates the role of non additive gene action in controlling this trait which is in conformity with the findings of Senthilkumar (1998).

Fruit girth

The cross AA×MDU1 alone recorded positive significant heterosis in all the three basis for fruit girth while the cross AA×PK recorded significant value for heterobeltiosis alone (4.66%). Similar results for fruit girth were reported by Senthilkumar (1998) and Saravanan (2001). Inbreeding depression in F_2 and F_3 generations of the crosses AA×PK and AA×MDU1 were found to be significant whereas residual heterosis values for all the three crosses in both the generations was found to be non-significant and in the negative direction indicating the predominance of non additive gene action for this trait. This corroborates with the reports of Senthilkumar (2008).

Table 1 : Mean performance for yield and yield component characters in okra.

Generation	Crosses	Days to first flower	Plant height	Internode length	Number of nodes per plant	Number of fruits per plant	Fruit length	Fruit girth	Fruit weight	Fruit yield per plant
P	AA	40.04	103.46	4.62	23.60	22.80	13.33	6.01	17.46	387.40
	PK	42.07	103.46	6.93	16.73	11.53	11.63	5.69	25.34	368.73
	MDU 1	39.40	102.20	6.53	15.27	15.53	12.89	5.80	20.28	379.93
F_1	C1	39.80	116.13	7.87	21.20	24.80	13.81	6.29	37.50	492.33
	C2	40.13	102.93	7.58	28.07	29.60	22.89	6.49	37.17	520.40
	C3	39.82	106.73	7.77	21.80	17.27	21.91	5.71	39.94	487.00
F_2	C1	40.08	118.37	6.20	21.36	15.33	13.05	5.46	23.72	450.34
	C2	40.19	108.66	7.49	23.88	17.08	13.42	5.42	27.75	461.21
	C3	41.61	128.50	6.92	19.52	14.66	13.17	5.52	31.48	437.68
F_3	C1	40.14	120.72	6.43	21.10	15.38	12.87	5.51	24.47	449.64
	C2	39.78	104.96	7.16	23.38	17.42	12.55	5.39	24.91	443.99
	C3	39.93	116.79	6.90	18.79	14.71	12.59	5.48	30.67	429.33

C1 : Arka Anamika × Parbhani kranti; C2 : Arka Anamika × MDU 1; C3 : Parbhani Kranti × MDU 1.

Fruit weight

In F_1 generation, all the three hybrids showed positive significant heteroses and the standard heterosis for fruit weight ranged from 79.27 (AA×PK) to 160.37 (PK×MDU1). Similar result for the trait fruit weight was reported by Mehta (2007) and Bhoovaragamoorthy (2008). High inbreeding depression in F_2 and F_3 generations was recorded by the crosses AA×MDU1 and PK×MDU1. Significant residual heterosis ranging from 21.34 to 44.63% was noted in F_2 generation for all the three crosses. The retention of heterosis may be due to the occurrence of transgressive segregants and close linkage of some favourable genes controlling these attributes. Khan *et al.* (2007) and Khan *et al.* (2009) also opined that F_1 hybrids with high heterosis were also associated with higher inbreeding depression.

Fruit yield per plant

The cross AA×PK recorded significant heterosis for fruit yield per plant in all the three bases of heterosis. High heterosis for this trait was also reported by Kulkarni and Virupakshappa (1977), Changani and Shukla (1986), Shukla and Gautam (1990), Mehta (2007) and Weerasekara *et al*. (2008). The crosses AA×MDU1 and PK × MDU1 registered significant relative and standard heterosis along with significant inbreeding depression in F and F_3 generations. The heterobeltiosis values ranged from 0.85 to 27.09%. The residual heterosis was found to be non-significant for the above said crosses while it was significant in the cross AA×PK in both generations. Inbreeding depression was non-significant in the cross AA×PK and significant in the remaining two crosses. High heterosis along with inbreeding depression in the cross AA×MDU1 and PK×MDU1 showed that the trait fruit yield per plant was influenced by non additive gene action in these crosses. This could be exploited for heterosis breeding method. Similar result was observed by More and Patil (1997) for this trait.

The F_1 hybrid AA×PK which registered significant heterosis and residual heterosis in F_2 and F_3 generations had non-significant inbreeding depression in both the segregating generations indicating the predominance of additive gene action for this trait. Saravanan (2001) and Bhoovaragamoorthy (2008) reported the role of additive gene action in controlling this trait. The presence of hybrid vigour for fruit yield per plant in F_2 and F_3 may be attributed to additive and additive × additive interaction and such cross was expected to give superior segregants which may be handled through pedigree breeding method.

High correlation between midparental heterosis and inbreeding depression was observed for all the traits under study. Residual heterosis also showed similar trend with midparental heterosis for all the traits which might be due to the presence of additive gene action.

Since, the industry of producing hybrid seed of bhendi is not adequately developed in India, search for the crosses manifesting heterosis largely due to additive type of gene effects should be attempted to make use of residual heterosis. The results of number of studies have indicated the possible advantage of utilizing F_1 generation of hybrids in various crops. These results confirm the

Table 2 : Heterosis and inbreeding depression for yield and yield component characters in okra.

Characters	Crosses	Heterosis (%) (F_1)			Residual heterosis (%)		Inbreeding depression(%)	
		Relative heterosis	Heterobeltiosis	Standard heterosis	F_2	F_3	F_2	F_3
Days to first flower	C1	-3.49**	-5.42**	-5.42**	-2.81**	-2.67**	-0.70	-0.85
	C2	0.58	-0.67	-4.61**	0.73	-0.30*	-0.15	0.87
	C3	-2.30**	-5.40**	-5.50**	2.15**	-1.98**	-4.55	-0.33
Plant height	C1	8.19*	2.34	14.75**	10.28**	12.47**	-1.93	-3.95
	C2	-8.78**	-9.29**	1.71	-3.70	-6.98	-5.57	-1.97
	C3	0.03	-4.88	5.46	20.43*	9.46	-20.40**	-9.43
Internode length	C1	36.16**	13.56*	13.56*	7.27	11.25	21.22	18.30**
	C2	35.96	16.08	9.38	37.94	28.61	-1.45	5.41
	C3	15.45**	12.12*	12.12*	2.82	2.53	10.94*	11.20*
Number of nodes per plant	C1	5.11	-10.17	26.72	5.90	4.61	-0.75	0.47
	C2	44.43**	18.94**	67.78**	22.87**	20.30**	14.93**	16.71**
	C3	36.25**	30.30**	30.30**	22.00**	17.44**	10.43**	13.81**
Number of fruits per plant	C1	44.44*	8.77	115.09**	-10.72	-10.43	38.19*	37.98*
	C2	54.45**	29.82**	156.72**	-10.88**	-9.11*	42.30**	41.15**
	C3	27.64**	11.20*	49.78**	8.35	8.72	15.11**	14.82**
Fruit length	C1	10.66**	3.60	18.74**	4.54	3.12	5.50*	6.81*
	C2	74.60**	71.72**	96.82**	2.36	-4.27	41.31**	45.17**
	C3	78.71**	69.98**	88.39**	7.42	2.69	39.89**	42.54**
Fruit girth	C1	7.52	4.66**	10.54	-6.67	-5.81	13.20*	12.40*
	C2	26.84*	24.63*	31.63*	-8.21	-8.72	27.64*	28.04*
	C3	-0.78	-1.72	0.18	-4.09	-4.44	3.33	3.68
Fruit weight	C1	67.68**	57.50**	79.27**	44.63*	49.21*	13.75	11.02
	C2	62.53**	31.44**	142.31**	21.34*	8.92	25.34**	32.98**
	C3	83.13**	41.23**	160.37**	44.34**	40.58**	21.18**	23.23**
Fruit yield per plant	C1	30.22**	27.09**	33.52**	19.12*	18.93*	8.53	8.67
	C2	20.00**	8.43	41.13**	6.35	2.38	11.37*	14.60*
	C3	14.06*	0.85	31.26**	3.13	1.18	9.59*	11.30*

* Significant at 5 per cent level, ** Significant at 1 per cent level.
C1 : Arka Anamika X Parbhani kranti; C2 : Arka Anamika X MDU 1; C3 : Parbhani Kranti X MDU 1.

reports of earlier workers (Brim and Cockerham, 1961; Singh, 1979; Ganesan, 1995; Senthilkumar, 1998). Although, the extent of heterosis retained in F_2 progeny cannot be expected to the same degree as in F_1, it should be economically significant (Senthilkumar, 1998).

Conclusion

Inbreeding depression was high in good performing hybrids. Highest yielding F_1 hybrids yielded lesser in the subsequent generation due to overdominance and inbreeding depression, whereas moderate yielding F1 hybrids were found to be more stable even passing through process of segregation due to additive gene action. Soomro and Kalhoro (2000) and Khan *et al.* (2007) also manifested that F_1 hybrids with high heterosis were also associated with higher inbreeding depression.

It is also suggested that combined performance of F_1 and F_2 hybrids could be a good indicator to identify the most promising populations to be utilized either as F2 hybrids or as a resource population for further selection in advanced generations. F_2 hybrids having extraordinary performance could also be used as such to boost up the yield as also mentioned by Khan *et al*. (2007).

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