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INHERITANCE STUDIES OF SOME ECONOMIC CHARACTERS IN OKRA (*Abelmoschus esculentus* (L.) Moench)

[ESTUDIOS SOBRE LA HEREDABILIDAD DE ALGUNOS CARACTERES ECONÓMICOS DE LA OCRA (*Abelmoschus esculentus* (L.) Moench)]

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SUMMARY

The inheritance of number of pods per plant, number of days to flowering and plant height in okra were investigated. Two okra cultivars, namely 'Kosti' and the Indian cultivar 'Pusa Sawani' were used in this study. The two parents were selfed for three successive generations to fix the characters under study. Crosses were made between the two parents, and reciprocal F_1's, F_2's and all possible backcrosses were derived from the initial crosses. The experiment was carried out at Shambat, Sudan in a randomized complete block design with three replications. Gene effects, heritability in broad and narrow sense, number of effective factors and genetic advance were determined. No reciprocal differences were found between F_1 and F_2 generation for all the characters studied. Three parameter additive-dominance model utilizing generation means was used to estimate gene effects. The results indicated that most of the genetic variance was accounted for by additive and dominance gene effects, with evidence of epistasis. High genetic variability, high heritability values and genetic gains support the above conclusions regarding the inheritance of these characters.

Key words: Okra; gene effects; genetic advance; heritability; number of pods per plant; plant height.

RESUMEN

Se estudio la heredabilidad de los caracteres: número de vainas por planta, días a la floración y altura de planta para los cultivares de ocra Kosti y Pusa Sawani. Las líneas parentales fueron autopolinizadas para por tres generaciones sucesivas para fijar los caracteres estudiados. Se realizaron cruzas entre las líneas parentales y los reciprocos F1 y F2 así como todas las posibles retrocruzas derivadas de las cruzas iniciales. Efectos génicos, heredabilidad, número de factores efectivos y ganancia genética fueron determinados. No se encontró diferencias reciprocas entre las generaciones F1 y F2. Se empleó un modelo de tres parámetros de aditividad-dominancia para estimar los efectos génicos. Los resultados indicaron que la varianza genética fue explicada principalmente por efectos de aditividad y dominancia con evidencia de epistasis. Una alta variabilidad genética, altos valores de heredabilidad y ganancia genética apoyan las conclusiones en relación a la heredabilidad de estos caracteres.

Palabras clave: Ocra; efectos génicos; ganancia genética; heredabilidad; número de vainas; altura de planta

INTRODUCTION

The cultivated okra (*Abelmoschus esculentus* (L.) Moench) is an important vegetable crop throughout tropical and subtropical regions of Asia and Africa (Bight and Bhat, 2006). The tender pods of okra are used in stews or cut into slices, sundried, then ground as a powder and used as a favourite Sudanese dish called "Weika" (Abdelmageed, 2010). Similarly, the older immature pods which start to develop fiber are also cut into slices, sundried, ground and cooked. Even the young leaves are used as a vegetable and also may be dried. In other countries the pods are used in stews and soups. In the Sudan, a number of local mixed cultivars, Indian and American introductions are grown in the irrigated areas. The local cultivars are known as "Baladi" and each cultivar is named after the area from which it is collected. These cultivars show a lot of variability in many characters, such as yield, number of days to flowering, number of pods and plant height. Some of these cultivars are characterized by the presence of spines and stickiness of pods.

Despite the increase in vegetable production, yet the production doesn't meet the demand of the population.

Production of okra in Sudan was estimated as 216950 million Mt in 2007 according to FAO statistics (FAOSTAT, 2007). Consequently, any attempt to increase productivity would certainly be of value. In case of okra, it is of great importance to seek better cultivars than those presently grown. Though improved crop cultivar is one of the pre-requisites for high yield, little breeding has been done on okra in the Sudan, with this consideration in mind; this study was carried out to study the mode of inheritance of number of days to flowering, number of pods per plant and plant height and to investigate if there is any “maternal effect” and its magnitude for these characters.

MATERIALS AND METHODS

The experiment was carried out, at the Demonstration Farm of the Faculty of Agriculture, Shambat, Sudan (Latitude 15° 40' N and Longitude 32° 32' and 380 meters above sea level altitude). The experimental site is categorized as hot dry region, which could be represents a suitable region for the production of okra. Hence, the test genotypes could express their full genetic potentials for the characters investigated here. Two cultivars were selected on the basis of the presence of wide differences between them with respect to certain economic characters, namely number of pods per plant, number of days to flowering and plant height. The Indian cultivar ‘Pusa Sawani’ (PU) and ‘Kosti’ (KO) were used as parental lines in this experiment. Ten healthy plants of each parental line were chosen randomly and selfed by bagging the floral buds in the afternoon prior to their opening the following morning i.e at 4 p.m. for three successive generations i.e June 1996, October 1996 and March 1997 to produce pure inbred lines and to fix the characters under investigation. The two parental inbred lines, namely (PU) and (KO) were reciprocally crossed generating F_1 populations F_1 (PU), and F_1 (KO) (PU and KO designate the female parent in the cross) from which later generations were derived. The two reciprocal F_2’s and the eight possible backcrosses were obtained. In July 1998, July 1999 the following generations were planted, namely parents, F_1, F_2, backcrosses and their reciprocals in a randomized complete block design with three replicates, using 5-ridges plots of 4x4 meters with 75 cm between the ridges and 30 cm between plants, 3-4 seeds were sown per hole. Two weeks from sowing, the plants were thinned to two plants / hole. All the necessary cultural practices and protection measures were adopted for raising good crop.

Data collection

Prior to flowering, ten plants were selected at random from each plot of the parents (P_1 and P_2) and $F_1^{'}$s. For backcrosses and their reciprocals, thirty plants from each replication were chosen randomly, while for the $F_2^{'}$s generations, sixty plants in each replication were selected at random and the following parameters were recorded on the selected plants: Plant height (cm): after the last picking the plant height was measured from the ground level to the tip of the stem, number of pods per plant: all mature pods for each plant in each genotype were counted and average was calculated and number of days to flowering: measured as the number of days from seeding to first flower anthesis.

Statistical analysis

Because the results of the two seasons were similar, the data were pooled over seasons and reanalyzed. The recorded data of the different generations was subjected to analysis of variance according to the procedure described by Gomez and Gomez (1984). Duncan’s multiple range test was used for the separation of means of the different generations as described by Steel and Torrie (1960) to determine differences between generation means and differences in the reciprocals crosses to detect if there is any maternal effects on these traits. Since the reciprocals were not significantly different the data were pooled for analysis. Further, the gene actions were estimated according to the procedure of the three-parameter additive-dominance model developed by Mather and Jinks (1971, 1977). Consequently, the data obtained from the different generations of the cross between the parents were used to estimate the model parameters (m), (d) and (h); where the mid-parental value (m) is the point of origin for measuring the difference between two homozygous parents and (d) and (m) represent sums of the additive and dominance effects, respectively. The adequacy of the model to describe the variation within the cross was then tested by the procedure of the joint scaling test proposed by Cavalli (1952) and illustrated by Alexander and Rowe (1980). Thus, expected generation means were derived from the estimates of the genetic parameters (m), (d) and (h). The expected means were then compared with the observed ones, using the chi-square test, to assess the agreement between them**.**

Minimum number of effective factors (gene) was estimated using Castle / Wright formula (Weber, 1950) and Wright's formula (Burton, 1951). Estimates of heritability were calculated using Burton’s method (1951), Warner’s method (1952) and Hanson’s et al. method (1956). The Genetic advance (GA) was calculated, assuming the selection of the top 5% of the population, as proposed by Johnson et al. (1955).

RESULTS

The mean squares from the analysis of variance, the grand mean (G.M) and coefficient of variation (C.V) of the different economic characters studied for different generations are shown in Table 1. Highly significant differences (P=0.01) were indicated for these economic characters among the different generations (P_1, BC_{11}, F_1, F_2, BC_{12} and P_2).

Nature of gene action, heritability, genetic advance, and number of effective factors

Regarding the number of days to flowering, the parental lines showed a significant difference in number of days to flowering (Table 1). The parent PU reached flowering in less number of days. The reciprocal F_1's were not significantly different from each other, and their means were lower than the mid-parental value (58.83). Reciprocal F_2's showed no significant difference and their mean value (57.49) was significantly above the F_1's value (54.12). The estimated values of $\underline{m}$, $\underline{d}$, and $\underline{h}$ together with the observed and expected means are presented in Table 6. Highly significant and positive value for $\underline{m}$ was obtained; both $\underline{d}$ and $\underline{h}$ were negative and significant. The number of genes was less than one for Castle/Wright formula and more than one for Wright formula (Table 3). Heritability percentages estimates are presented in Table 3. Burton's, Hanson's *et al.* and Warner's methods gave estimates of 79.68, 52.04 and 90.07 percent respectively. Genetic advance from selecting the highest 5 percent of the F_2 plants was 14.57 when using heritability estimated by Hanson's *et al.* method.

With respect to number of pods per plant, comparisons of the means of the parents, F_1, F_2, and backcross generations are presented in Table 1. The difference in the number of pods per plant between the two parents was highly significant. The reciprocal F_1's were not significantly different from each other, and their means were greater than the mid-parental value (7.47). Reciprocal F_2's showed no significance difference and their mean value (7.79) was not significantly different and below the F_1's value (11.55). The estimated values of $\underline{m}$, $\underline{d}$ and $\underline{h}$ together with the observed and expected means are shown in Table 7. Highly significant and positive value for $\underline{m}$ was obtained; both $\underline{d}$ and $\underline{h}$ were positive and significant, but $\underline{d}$ was less than $\underline{m}$ and more than $\underline{h}$. The number of genes was estimated using Castle/Wright and Wright formulae are shown in Table 4, with values less than one. Heritability percentages estimates are presented in Table 4. Burton's, Hanson's *et al*. and Warner's methods gave estimates of 89.99, 96.39 and 73.10 percent respectively. The expected genetic gain in the next generation due to selection of the highest 5 percent F_2 plants was 88.10 using heritability estimated by Hanson's *et al.* method.

Concerning plant height, comparisons of the means of the parents, F_1, F_2 and backcross generations are illustrated in Tables 1 and 8. The difference in plant height between the two parents was highly significant. The reciprocal F_1's showed no significant difference between each other, their means were greater than the mid-parental value (104.97 cm). Reciprocal F_2's showed no significant differences, their mean value (86.10 cm) was significantly below the F_1's mean (122.50 cm). The estimated values of $\underline{m}$, $\underline{d}$ and $\underline{h}$ together with the observed and expected means are presented in Table 8. Highly significant and positive value of $\underline{m}$ was obtained; $\underline{d}$ value was positive and significant but about half that of $\underline{m}$, a reflection of its rather large contribution; $\underline{h}$ value was positive but is not significant. The number of genes estimated using Castle/Wright and Wright formulae are presented in Table 5, with values of 3.09, 2.37 and 3.36 respectively. Heritability percentages estimates are summarized in Table 5. Burton's, Hanson's *et al*. and Warner's methods gave estimates of 90.04, 97.00 and 78.19 percent respectively. Genetic gain estimated using heritability was generally high when the 5 percent of the highest F_2 individuals were selected; the highest gain expected as percent of the mean was 39.68 using heritability estimated by Hanson's. *et al*. method.

DISCUSSION

Inheritance of some economic characters of okra

Number of days to flowering, number of pods per plant and plant height of okra represent important characters that have a contribution to the yield of okra. For the genetic improvement of okra, knowledge of the genetic basis that influences the expression of these characters is essential for effective selection and improvement of the crop. Hence, the present study was carried out to study the mode of inheritance of these economic characters and to investigate any maternal effects. The highly significant differences detected between the different generations mean i.e. P_1, P_2, F_1, BC_{11}, BC_{12} and F_2 indicated that these economic characters under study are genetically controlled.

Table 1. Duncan's multiple range test for number of days to flowering, number of pods per plant and plant height.

Population	Flowering	Pods	Height (cm)
PU	53.23 e*	11.70 a	151.33 a
F_1 PU	54.03 de	11.63 a	129.13 bc
F_2 PU	57.57 bcd	7.33 b	81.72 d
PU x F_1 KO	55.53 cde	10.69 a	126.05 bc
F_1 KO x PU	55.83 cde	10.18 a	123.95 bc
PU x F_1 PU	55.26 cde	10.45 a	133.91 ab
F_1 PU x PU	57.37 bcd	10.47 a	127.96 bc
F_1 KO	54.20 de	11.47 a	115.87 c
F_2 KO	57.41 bcd	8.24 b	90.47 d
KO x F_1 PU	63.39 a	5.93 c	64.24 ef
F_1 PU x KO	61.15 ab	7.06 bc	80.39 de
KO x F_1 KO	63.38 a	5.76 c	70.06 de
F_1 KO x KO	58.63 bc	6.46 c	78.77 de
KO	64.43 a	3.23 d	58.60 f
Mean	57.96	8.61	102.32
C.V.	3.52	10.25	8.90

* Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Nature of gene action

Mather's individual scaling test and Cavalli joint scaling test, which were used to test the adequacy of the additive-dominance model to describe the variation between the inbred lines, revealed that the model was inadequate for the cross for the following characters, namely number of days to flowering, number of pods per plant and plant height. The two methods were in complete agreement, indicating that epistasis was operative in the material under investigation for these traits. With regard to number of days to flowering, significant values of m, d and h were obtained. But both d and h showed negative sign. The negative sign (-) of h indicated that dominance was towards the parent that start flowering earlier than the other parent. Also this result indicates the importance of both additive and non-additive gene action beside epistasis in the inheritance of this trait. Significant values of m, d and h were observed regarding number of pods per plant and the value of d was more or less equal to h. This indicates the importance of additive, dominance gene action and epistasis in the control of this trait. Significant values of m and d were observed regarding plant height, but the value of d was equal five times or more the value of h, which indicates the predominance of additive gene effects. Thus as a conclusion plant height is under the control of additive gene effects and epistasis. The results of number of days to flowering, confirmed those obtained by Kulkarni *et al*. (1978), Kulkarni and Swamy Rao (1978) and Arumugam and Muthukrishnan (1979) who reported the importance of epistatic gene interaction for number of days to flowering. The results of numbers of pods per plant confirmed those obtained by Kulkarni *et al*. (1978). The results of plant height confirmed those obtained by Kulkarni *et al*. (1978); Arumugam and Muthukrishnan (1979) and Rajani et al. (2001) who indicated the operation of both additive and non-additive gene effects.

Table 2. Total variances and their expected components for the different generations of okra for number of days to flowering, number of pods per plant and plant height, reciprocals combined.

	Flowering	Pods	Height (cm)	Expectation
P_1	3.219	1.389	34.286	E
P_2	6.254	0.598	19.766	E
F_1	3.134	2.387	64.775	E
F_2	20.68	14.56	412.802	1/2D+1/4H+E
BC_{11}	13.086	9.0896	291.477	1/4D+1/4H+E
BC_{12}	17.518	9.3940	211355	1/4D+1/4H+E

Where :

E = environmental variance

D = The additive variance.

H = The dominance variance.

Heritability and genetic advance

Heritability values are expressed in percent. If the estimated heritability value (h^2) is high (close to 100 percent), the observed variability is mostly must due to genetic factors. If the heritability value is low, the observed variation is mainly due to environmental factors and little gain can be expected from selection in the particular population for the given character. Burton's method (1951) and Hanson *et al*. (1956) method were used to estimate heritability in broad sense and Warner's method (1952) was used to estimate heritability in narrow sense in this experiment.

Table 3. Heritability, number of effective factors and possible genetic advance under selection for number of days to flowering.

Statistic		Estimated value
Heritability		
1. Burton's method		79.68 [b]
2. Warner's method.		52.04 [n]
3. Hanson's *et al* .method.		90.07 [b]
Number of effective factors		
1. Castle / Wright formula		
a. using F_2 data		0.893
b. using backcross data.		0.788
2. Sewell Wright formula		1.21
Expected genetic advance when 5% F_2 selected		
Burton's h^2	in days	7.47
	as percent	12.89
Warner's h^2	in days	4.88
	as percent	8.42
Hanson's *et al*. h^2	in days	8.44
	as percent	14.57

[b] Broad sense heritability
[n] Narrow sense heritability

With regard to number of pods per plant and plant height, the different methods used for estimation of heritability offered a chance for comparison. Both Burton's method (1951) and Hanson's *et al*. (1956) method gave high estimates of heritability in broad sense. These estimates were high but have been biased upward by non-additive and epistatic interactions. The high heritability values give added support to the small number of major genes conditioning these economic characters. Warner's method (1952) estimated the narrow sense heritability and this was lower than the broad sense heritability estimate. This is due to the inflating effect of dominance and epistasis, which is usually associated with the latter and the dependency of narrow sense heritability on additive variance only. As expected with such high heritability values, the estimated genetic gain was equally high using the three estimates of heritability. High genetic gain accompanied by high or reasonably high h^2 would indicate that additive gene effects are possibly more important for these economic characters than non-additive effects (Johnson *et al.*, 1955; Panse, 1957). Therefore, simple selection is expected to be fruitful in okra improvement for these traits, where high heritability and high expected genetic advance were demonstrated. This result is in accordance with that obtained by Kiran Patro and Ravisankar (2004). Number of pods per plant exhibited high heritability estimates and relatively high genetic advance. This finding was in accordance with that reported by Mahajan and Sharma (1979); Mishra and Chhonkar (1979) and El-Maksoud *et al*. (1984). Plant height showed high heritability estimates and high genetic advance. This result was in accordance with that of Padda *et al*. (1970); Swamy Rao (1972); Singh and Singh (1979) and Palaniveluchamy *et al*. (1982). Moderately high to low heritability, accompanied with low genetic advance, was observed for number of days to flowering, which might be due to non-additive gene effects (Panse, 1957). Hence, little improvement by selection is likely in this character. This finding was in agreement with the results obtained by Swamy Rao and Sathyavathi (1977); Mishra and Chhonkar (1979) and El-Maksoud *et al*. (1984).

Table 4. Heritability, number of effective factors and expected genetic advance under selection for number of pods per plant.

Statistic		Estimated values
Heritability		
1. Burton's method		89.99 [b]
2. Warner's method		73.10 [n]
3. Hanson's *et al*.method.		96.39 [b]
Number of effective factors		
1. Castle / Wright formula		
a. using F_2 data		0.74
b. using backcross data		0.64
2. Sewell Wright formula		0.13
Expected genetic advance when 5% of F_2 selected		
Burton's h^2	in pods	7.08
	as percent	82.25
Warner's h^2	in pods	5.75
	as percent	66.81
Hanson's *et al*. h^2	in pods	7.59
	as percent	88.10

[b] Broad sense heritability
[n] Narrow sense heritability

Table 5. Heritability, number of effective factors and expected genetic advance under selection for plant height.

Statistic		Estimated values
Heritability		
1. Burton's method		90.40 [b]
2. Warner's method.		78.19 [n]
3. Hanson's *et al.* methods		97.00 [b]
Number of effective factors		
1. Castle / Wright formula		
a. using F_2 data		3.09
b. using backcross data		2.37
2. Sewell Wright formula		3.60
Expected genetic advance when 5% of F_2 selected		
Burton's h^2	in cm	37.84
	as percent	36.98
Warner's h^2	in cm	32.73
	as percent	31.99
Hanson's *et al*. h^2	in cm	40.60
	as percent	39.68

[b] Broad sense heritability
[n] Narrow sense heritability

Number of effective factors

For estimation of the number of effective factors, differences between parents and variation in F_2 and backcrosses are needed. The Castle/Wright formula (Weber, 1950) and Wright formula (Burton, 1951) were used to estimate the number of effective factors. With regard to number of pods per plant, when using both formulae, an estimate of genes number was below one. These values should be considered as one and probably more. This may be due to the existence of interaction between pertinent non-allelic genes. For number of days to flowering an estimate of gene number was below one when using Castle/Wright formula and more than one when using Wright formulae. This low estimation might be due the interaction of non-allelic genes in material under study. Also these genes may be segregated as one unit (Mather, 1949; Cooke and Mather, 1962). With regard to plant height estimates of the effective factors when using Castle/Wright and Wright formulae were 3.09, 2.37 and 3.36 pairs of genes respectively, suggesting that the parental varieties differed in three pairs of genes. Thus, the number of effective factors might not be the actual number of genes due to the existence of interaction of non-allelic between the pertinent genes and dominance. This result is in accordance with that reported by Swamy Rao (1979) who reported that plant height was under the control of polygenes. Allard (1960) noted that major genes are believed to have a complement of modifiers and may be the case in the inheritance of the characters reported here. It should be remembered that the number of genes estimated is not necessarily the actual number. Each effective unit may be considered as a block of closely linked genes which segregate as a unit.

Maternal effect

Generally, in all generations, for the different characters, no reciprocal differences were detected, indicating the absence of maternal influence for these characters. These findings confirmed the results obtained by Lee *et al.* (1968) that, in plant species, maternal effect appears to be fairly rare.

Table 6. Observed and expected values for P_1, P_2, F_1, F_2, BC_{11} and BC_{12} generations and estimates of mean effects (m), additivity (d), dominance (h) for number of days to flowering, reciprocals combined.

Generation	Observed	Expected	Deviation	Component	Estimates	T- Value
P_1	53.23	54.21	-0.98	m	59.05 ±1.11	53.12 **
P_2	64.43	65.57	-1.14	d	-5.68 ± 1.08	5.25 **
F_1	54.12	55.38	-1.26	h	-4.52 ± 1.93	2.35 **
F_2	57.49	57.63	-0.14			
BC_{11}	55.99	54.79	1.20			
BC_{12}	61.64	60.47	1.17			

$\chi^2_{(d..f=3)} =$ 26.45 (Prob. < 0.001)
** Significant at 5% level.

Table 7. Observed and expected values for P_1, P_2, F_1, F_2, BC_{11} and BC_{12} generations and estimates of mean effect (m), additivity (d), dominance (h) for number of pods per plant, reciprocals combined.

Generation	Observed	Expected	Deviation	Component	Estimates	T- Value
P1	11.70	11.17	0.53	m	7.03 ±0.59	11.92 **
P2	3.23	2.89	0.34	d	4.15 ± 0.57	7.28**
F1	11.55	10.56	0.99	h	3.54 ± 1.11	3.19 **
F2	7.79	8.79	-1.00			
BC_{11}	10.45	10.87	- 0.42			
BC_{12}	6.30	6.72	- 0.42			

$\chi^2_{(d..f=3)} =$ 13.99 (Prob = 0.01 - 0.001)
**significant at 5% level

Table 8. Observed and expected values for P_1, P_2, F_2, BC_{11} and BC_{12} generations and estimates of mean effect (m), additivity (d), dominance (h) for plant height, reciprocals combined.

Generation	Observed	Expected	Deviation	Component	Estimates with standard deviation	T- Value
P_1	151.33	146.85	4.48	m	99.19 ± 8.95	11.08 **
P_2	58.60	51.53	7.07	d	47.65± 8.70	5.48**
F_1	122.50	109.09	13.41	h	9.91± 16.91	0.59
F_2	86.10	104.14	-18.04			
BC_{11}	127.97	127.97	0.00			
BC_{12}	73.37	80.31	-6.94			

$\chi^2_{(d..f=3)} =$ 618.96 (Prob. < 0.001)
** significant at 5% level.

Table 9. Individual scaling test on the data from crosses of the two inbred line 'Pusa Sawani' and 'Kosti' for number of days to flowering, number of pods per plant and plant height.

	Number of days to flowering	Number of pods per plant	Plant height (cm)
A±S.E	4.630±0.552	-2.350±0.444	-17.890±2.355
B±S.E	4.730±0.675	-2.180±0.408	-34.360±2.028
C±S.E	4.060±1.202	+3.770±0.962	-110.530±4.957

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