Australian Journal of Basic and Applied Sciences, 6(10): 36-41, 2012
ISSN 1991-8178

Combining Ability and Heterosis for Yield and Yield Components in Maize (*Zea mays* L.)

[1]Atif Ibrahim Abuali, [2]Awadalla Abdalla Abdelmulla, [3]Mutasim M.Khalafalla, [4]Atif Elsadig Idris and [5]Abdellatif Mohammed Osman

[1]Desertification Research Institute, National Centre for Research, P.O. Box 2404, Khartoum, Sudan.
[2]Department of Agronomy, Faculty of Agriculture, University of Khartoum, Shambat, P.O.Box. 13314, Khartoum, Sudan.
[3]Commission for Biotechnology and Genetic Engineering, National Centre for Research, P.O.Box. 2404, Khartoum, Sudan.
[4]Department of Agronomy, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum North, Shambat, P.O.Box. 71, Khartoum, Sudan.
[5]Department of Science, Faculty of Education, Blue Nile University, Damazin, Sudan.

Abstract: The study was conducted at two sites , University of Khartoum the experimental farm, faculty of Agriculture, Shambat and at west of Khartoum state, Elrawkeeb Dry Land Research Station, Sudan, during the summer and winter seasons of 2009 and 2010 respectively. Five inbred lines (2, 3, 6, 277, and 405) were used as lines and two inbred lines namely (66Y and 160) were used as (testers). These lines were crossed together according to line x tester technique to generate 10 F_1- hybrids, every genotype was planted in rows with 4 m along, 70cm between rows and 25cm between plants. A line × tester method for estimation the general combining ability (GCA) of parent and specific combining ability (SCA) of their F_1-hybrids was used. Genetic components resulting from additive and non-additive type of gene action were also estimated. Heterosis was measured as a deviation from the mid-parents and better- parent. The analysis of variance for combining ability revealed that both GCA and SCA variances were highly significant for most of the studied characters indicating importance of additive as well as non- additive types of gene action in controlling these traits. GCA mean squares for inbred lines were significant ($P < 0.01$) for all the traits except cob length and number of kernels/row while GCA due to testers was only significant ($P<0.05$) for 100- kernels weight. Moreover, variances due to SCA were higher in magnitude than GCA for the yield and yield components except cob diameter, number of rows/cob, number of kernels/row and harvest index. GCA to SCA ratios were less than one for most of the traits except cob diameter, number of kernels row/cob, number of kernels/row and harvest index indicating a preponderance of additive over no additive gene action. High positive heterosis for grain yield and its components was found for more than half of the hybrids studied. Crosses involving 160×3 and 66Y×2 produced the highest heterosis. It can be concluded that these parental lines can be desirable parents for hybrids as well as for inclusion in breeding program, since they may contribute favorable alleles in the synthesis of new varieties

Key words: Maize, General combing ability, Specific combing ability, Heterosis, Grain yield.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop in the world after rice and wheat. It is cultivated in a wider range of environments than wheat and rice because of its greater adaptability (Koutsika-Sotiriou, 1999).Over 70% of maize in Africa is produced by resource poor small-scale farmers (Salasya *et. al.,* 1998). The average maize yield in Africa stood at 1.3 t/ha compared to 3.0 t/ha elsewhere (FAO, 2006). The low grain yields can be attributed to a number of constraints which include biotic stress (diseases, pests and lack of suitable varieties), a biotic stresses (low soil fertility and lack of capital to purchase farm inputs) (Salasya *et. al.,* 1998). In the Sudan, maize is normally grown as a rain fed crop in Kordofan, Darfur and Southern states or in small-irrigated areas in Northern states (Ahmed and Elhag, 1999). Recently, there has been an increased interest in maize production in the Sudan (Nour *et al*, 1997). Heterosis and combining ability is prerequisite for developing a good economically viable maize variety. Information on the heterotic patterns and combing ability among maize germplasm is essential in maximizing the effectiveness of hybrid development (Beck *et al*.1990). In maize, appreciable percentage of heterosis for yield and combining ability were studied by several workers (Roy *et al*., 1998; Paul *et al*., 1999 and Rokadia., 2005).

Combining ability studies provide information on the genetic mechanisms controlling the inheritance of quantitative traits and enable the breeders to select suitable parents for further improvement or use in hybrid breeding for commercial purposes. In biometrical genetics two types of combining abilities are considered i.e.

Corresponding Author: Atif Elsadig Idris, Department of Agronomy, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum North, Shambat, P.O. Box 71, Khartoum, Sudan.
E-mail: atifelsadig@yahoo.com

general combining ability (GCA) and specific combining ability (SCA). General combining ability refers to the average performance of the genotype in a series of hybrid combinations and is a measure of additive gene action whereas, specific combining ability is the performance of a parent in a specific cross in relation to general combining ability (Sharief *et al.,* 2009). SCA is due to genes showing non-additive effects (Sprague and Tatum, 1942). Line×tester mating design was developed by Kempthorne (1957), which provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations in applied breeding programs. The design has been widely used in maize breeding by several workers and continues to be applied in quantitative genetic studies in maize due to its significance (Sharma *et al.,* 2004). However, the objective of this study was to evaluate of combining ability and estimate the heterosis for yield and yield components of maize genotypes.

MATERIAL AND METHODS

Seven inbred lines were used in this study, five inbred lines (2, 3, 6, 277 and 405) were used as lines and two inbred lines namely (66Y and 160) were used as (testers). These lines were crossed together according to line x tester technique (Kempthorne, 1957) to generate 10 F_1 hybrids. Field evaluation of 17 genotypes (10 F_1 hybrids plus 7 parental inbred lines) was performed in two sites: El Rawakeeb Dry land and Desertification Research station. (National Center for Research, which west of Omdurman city Khartoum state, longitude 32º 15´ E, latitude 15º 25 ´N and 420 meters above the sea level) and the Experimental Farm of the Faculty of Agriculture, University of Khartoum, Shambat (Longitude 32º 32´ E., Latitude 15º 40´ N, and 380 meters above the sea level) during winter and summer seasons 2009 and 2010 respectively. The genotypes were laid out using spilt – plot design with three replications at the two sites. All recommended cultural practices and operations (planting, irrigation) were conducted. Different plant characters were measured, which included cob length, cob diameter, number of kernels/row, number of kernels/cob, 100 kernels/cob, cob weight, grain yield/plant, grain yield kg/ha and harvest index.

Data from each site was subjected to ANOVA separately to detect the significance of genotypic differences (Gomez and Gomez, 1984) before a combined ANOVA. Combining ability analysis was carried out according to Singh and Chaudhary (1979) based on line x tester general linear model for combined environments;

Yij = G + gi + gj + sij + ej j

Where; Yijk = performance of the hybrid when ith line is crossed to jth tester, G = overall mean, gi = general combining ability of ith line, gj = general combining ability of the jth tester, sij = specific combining ability when
ith line is crossed to jth tester and ej = random error term.

For estimation of combing ability. The pooled data of the four environments were analyzed for general combing ability (GCA) and specific combing ability (SCA) effects, as described by Singh and Chaudhary (1979).

Estimation of GCA:

$$\text{Lines} = \text{GCA (line)} = gi = \frac{XI\ldots}{tr} - \frac{X}{Itr}$$

$$\text{Testers} = \text{GCA (line)} = gt = \frac{XI\ldots}{Ir} - \frac{X}{Itr}$$

$$\text{Estimation of SCA effect} = Sij = \frac{xij}{r} - \frac{xi\ldots}{tr} - \frac{x.j}{Ir} + \frac{x\ldots}{Itr}$$

Where:

I= number of lines
T= number of testers
R = number of replications

Proportional contribution of lines, testers and their interaction line × tester to the total variances were calculated as follows:

$$\text{The contribution due to lines} = \frac{\text{ss due to lines}}{\text{ss due to crosses}} \times 100$$

The contribution due to line × tester = $\frac{\text{ss due to tester interaction}}{\text{Crosses ss due to}} \times 100$

Genetic parameters:

$\sigma^2 A$ =Additive variance:

$\sigma^2 l = [\, Ms\ (L) - Mse\ ] / rt = ½\, \sigma^2 A \qquad \sigma^2 A = 2\, \sigma^2 L$

$\sigma^2 t = [\, Ms\ (t) - Mse\ ] / rL = ½\, \sigma^2 A \qquad \sigma^2 A = 2\, \sigma^2 t$

Additive variance

$\sigma^2 A = [2\, \sigma^2 L + 2\, \sigma^2 t\ ] / 2 \quad = \sigma^2 l + \sigma^2 t$

$\sigma^2 D$ = Dominance variance

$\sigma^2 Lt = [\, Ms\ (Lx\ t) - Mse\ ] / r = \sigma^2 D$

Average degree of dominance (ā) was calculated according to the following equation:

$$\bar{a} = \sqrt{\frac{2\sigma^2 D}{\sigma^2 A}}$$

if ā = 0 no dominance
if ā = <1> 0 partial dominance
if ā = 1 complete dominance
if ā > 1 over dominance

Variance of general and specific combing ability was estimated according to (Singh and Chaudhary, 1979)
Heterosis**:** Using means computed from the combined analysis, percentage heterosis based on mid-parent(mp) and better parent (BP) values were been calculated according to the formula, using the following formula described by Davis(1978) as follows:

$$\text{Mid-parent heterosis (Mp)} = \frac{F_1 - ((P_1+P_2)/2)}{(P1+P2)/2} \times 100$$

$$\text{Better-parent heterosis (Bp)} = \frac{F_1 - BP}{BP} \times 100$$

Where: F_1= the mean of F_1 hybrid

P_1, P_2 and BP = means of the first, the second and better parent respectively.

RESULTS AND DISCUSSION

In the present study, mean squares due to lines were larger than due to tester (Table.1), indicating greater diversity among lines for most of the characters under study. Most of parental lines related to 160 and few of the 66Y revealed positive (GCA) (Table.2). Nevertheless, parental lines 2 and 6 were found most attractive general combiners. These parental lines can be desirable parents for hybrids as well as for inclusion in breeding program, since they may contribute favorable alleles in the synthesis of new varieties. Among the testers, the highest GCA values for grain yield (kg/ha) was revealed by tester 160. These results indicated that these inbred line (160) could be considered as good combiner for improving these traits. On the other hand, the analysis of variance for combining ability revealed that both GCA and SCA variances were highly significant for characters studied (Table.1), indicating importance of additive as well as non- additive types of gene action in controlling the traits. Furthermore, variances due to GCA were higher in magnitude than SCA for cob diameter, number of row/cob, number of kernels/row and harvest index (Table.1). Indicating importance of additive type of gene action for these traits. Similar finding were reported by, Seldom (1994), Mathur *et al.,* (1998), Ogunbodede *et al*. (2000) and Ismail (2004). On the other hand, cob length, number of kernels/cob, 100-kernels/cob, grain yield/plant and grain yield kg/ha only SCA variance was significant and also ratio of GCA/SCA was less than unity indicating the involvement of non-additive (Table.4). This suppresses the findings of Mohammad (1993) and Dehghanapour *et al*. (1997). Further more, in the present studies, the hybrids different widely and estimate of SCA effects showed that, the hybrids 160×3, 160×6, 66×277 and 66×405 were significantly superior to others in their specific combing ability for grain yield kg/ha (Table.3). These crosses could be selected and used inbreeding programs for improving these traits.

Table.4 indicates the value of additive gene effects was more than the value of dominance gene for cob diameters, number of rows/cob and number of kernels/rows, while the value of dominance gene effects was higher than the value of additive gene effects for cob length, number of kernels/cob, 100- kernels weight, grain yield/plant, grain yield kg/ha and harvest index. The average degree of dominance was more than one for number of kernels row/cob and number of kernels/row indicating this trait under control of the over dominance gene effect, whereas cob length, 100- kernels weight , grain yield kg/ha under control of complete dominance.

In the present study the results showed that, Heterosis estimates for most of the hybrids had positive mid-parents (MP %) and better parents (BP %) heterosis value for the yield and its component (Table.5). However, large number of hybrids showed superiority over their parents for various traits indicating the existence of substantial heterosis in the hybrids and the potential of these inbred lines for hybrid development. However, the ranges of heterotic responses observed in this study were on average higher than that reported by Gissa *et al.* (2007) for maize inbred lines. However, Tollenaar *et al.* (2004) observed higher mean grain yield MP of 167% and Betran *et al*. (2003) reported MP and BP of 157 and 126%, respectively, compared to130.92 % and 125.28%, observed in this study. The extent of heterotic response of the F_1 hybrids largely depends on the breeding value and genetic diversity of the parents included in crosses, and on the environmental conditions under which hybrids are grown (Hallauer and Miranda, 1988; Young and Virmani, 1990; Glover *et al.,* 2005).

Table 1: Mean squares from Line × Tester analysis of variance thirteen maize genotypes evaluated for different characters across during (Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010).

S.V	d.f	Cob length (cm)	Cob diameter (mm)	Cob weight (g)	No. of kernel rows/ cob	No. of kernels/row	No. of kernels per cobs	100 kernel weight (g)	Grain yield per plant (g)	Grain yield unit area (kg/ha)	Harvest index (%)
Rep	2	0.29ns	5.21ns	0.03ns	0.54ns	3.92ns	3704.08**	1.11ns	41.74ns	119072.12ns	0.50ns
Line (L)	4	0.31ns	7.21**	0.06**	1.03**	6.34ns	1424.93**	2.23**	224.25**	1017125.5**	44.00**
Tester (T)	1	0.45ns	0.42ns	0.03ns	1.20ns	2.21ns	1871.63ns	4.11**	0.32ns	46743.93ns	2.17ns
Line × Tester	4	1.27**	6.48**	0.02ns	1.02**	4.23ns	2144.04**	3.11**	454.68**	1256282**	42.00**
Crosses	9	0.75**	6.13**	0.16**	1.04**	4.94ns	1794.17**	4.02**	301.34**	1015597.1**	38.47**
Error	32	0.29	2.34	0.02	0.42	3.65	549.00	0.72	13.50	36434.82	2.56

* and **Significance at p=0.05 and p=0.01, respectively.

Table 2: Estimation of general combing ability effects of testers and lines genotypes for different characters a cross four environments (Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010).

S.V	Cob length (cm)	Cob diameter (mm)	Cob weight (g)	No. of kernel rows per cob	No. of kernels/row	No. of kernels/ cobs	100 kernels weight (g)	Grain yield/ plant (g)	Grain yield unit area (kg/ha)	Harvest index (%)
Testers										
66Y	0.12	-0.12	-0.10	-0.20	-0.27	-7.90	-0.37	-0.11	-39.47	-0.27
160	-0.12	0.12	0.10	0.20	0.27	7.90	0.37	0.11	39.47	0.27
Lines										
277	0.01	0.04	-0.66	0.22	-0.74	11.52	-0.16	-2.87	-230.48	-1.25
3	-0.36	0.93	0.56	0.49	-1.30	13.15	-0.38	1.79	-42.11	2.57
405	-0..01	-1.11	-4.60	-0.59	1.06	-25.31	-0.69	-7.22	-493.26	-3.71
2	0.11	1.23	-0.18	-0.19	0.05	-0.99	-0.03	-0.89	174.80	-0.30
6	0.25	-1.08	4.87	0.08	0.93	1.64	1.26	9.99	591.04	2.70

Table 3: Estimates of specific combing ability effects of F_1-hybrids for different characters over environments Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010.

Crosses	Cob length (cm)	Cob diameter (mm)	Cob weight (g)	No. of kernel rows/cob	No. of kernels/ row	No. of kernels/ cobs	100 kernels weight (g)	Grain yield / plant (g)	Grain yield unit area (kg/ha)	Harvest index (%)
66Y × 277	0.68	0.08	1.89	-0.48	1.15	-10.43	-0.97	6.66	240.80	2.04
66Y × 3	-0.10	-1.52	-5.73	-0.18	-0.88	-19.90	-0.56	-10.29	-484.32	-3.35
66Y × 405	-0.53	-0.34	3.25	0.41	-0.50	13.82	-0.15	1.78	138.85	0.93
66Y × 2	-0.24	0.98	4.82	0.46	0.59	25.54	0.82	9.53	562.34	-2.61
66Y × 6	0.19	0.96	-4.24	-0.20	-0.35	-9.03	-1.08	-7.68	-457.67	-2.22
160 × 277	-0.68	-0.08	-1.89	0.48	-1.15	10.43	0.97	-6.66	-240.80	-2.04
160× 3	0.10	1.52	5.73	0.18	0.88	19.90	0.56	10.29	484.32	3.35
160× 405	0.53	0.34	-3.25	-0.41	0.50	-13.82	0.15	-1.78	-138.85	-0.93
160× 2	0.24	-0.98	-4.82	-0.46	-0.59	-25.54	-0.82	-9.53	-562.34	2.61
160 × 6	-0.19	-0.96	4.24	0.20	0.35	9.03	1.08	7.68	457.67	2.22

Table 4: Percentages contribution of lines, testers and lines × testers to total variation among crosses for different characters and Genetic parameters values for studied characters.

	GCA		SCA		Genetic parameters		
Characters	Contribution due to lines	Contribution due to Tester	Contribution due to Lines × Tester	GCA/SCA	σ^2A	σ^2 D	ā
Cob length (cm)	18.26	6.64	75.10	0.33	0.27	0.33	1.29
Cob diameter (mm)	52.23	0.77	47.00	1.13	1.50	1.38	1.47
Cob weight (g)	34.13	0.04	65.83	0.52	0.01	0.00	#
No. of rows per cob	43.76	12.84	43.40	1.30	0.26	0.20	1.60
No. of kernels/ rows	57.03	4.96	38.01	1.63	0.80	0.19	2.88
No. of kernels/ cob	35.30	11.59	53.11	0.88	380.15	531.68	1.20
100- kernels weight (g)	37.10	11.36	51.54	0.94	0.73	0.80	1.35
Grain yield /plant (g)	32.93	0.01	67.06	0.49	69.37	147.06	0.97
Grain yield (kg/ha)	44.51	0.51	54.98	0.82	327584.15	406615.72	1.27
Harvest index (%)	50.84	0.63	48.53	1.06	13.79	13.15	1.45

Table 5: Magnitude of heterosis for the different characters in 13 maize hybrids expressed as percentage of increase over and decrease under mid- parent (MP%) or better parent (BP%) evaluated a cross four environments Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010**)**.

Crosses	Cob length (cm)		Cob diameter (mm)		Cob weight (g)		No. of kernel rows/cob		No. of kernels/ row		No. of kernels/ cobs		100 kernels Weight (g)		Grain yield / plant (g)		Grain yield unit area (kg/ha)		Harvest index (%)	
	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	BP%	MP%	HP%
66Y ×405	6.21	6.92	14.85	12.19	57.71	51.95	9.17	6.92	32.02	26.29	37.57	35.26	14.94	4.11	48.12	47.46	36.11	27.30	9.74	7.74
66Y ×277	28.31	5.13	11.18	5.50	67.17	56.14	7.91	5.13	30.69	36.44	47.02	40.80	25.84	23.43	67.17	55.38	53.83	42.71	29.38	26.51
66Y ×6	12.16	-7.82	14.46	11.83	69.81	63.87	8.09	-7.82	21.13	16.30	29.99	23.61	16.51	16.11	16.51	75.98	72.72	73.79	42.20	30.59
66Y ×2	4.63	2.98	18.70	12.16	77.75	59.31	9.83	4.83	21.03	15.80	32.55	18.02	18.64	14.38	86.31	71.55	81.32	60.77	48.88	41.08
66Y ×3	7.95	0.02	9.62	15.48	23.57	10.38	8.83	15.69	14.30	11.02	41.71	37.35	-4.28	-10.56	34.33	31.90	30.13	24.32	20.19	17.19
160× 405	16.22	14.26	12.39	4.69	13.83	11.95	-4.36	-11.17	34.73	23.85	17.30	3.96	32.97	7.99	31.76	29.10	31.76	17.52	2.37	-5.52
160× 277	16.88	4.35	7.30	6.87	39.12	36.94	7.83	0.67	15.20	6.23	44.90	25.48	15.22	13.82	19.25	27.10	30.95	23.25	11.01	2.08
160× 6	2.45	2.41	11.63	8.77	57.32	54.85	-3.20	-8.85	3.35	3.24	17.13	10.49	15.32	11.37	53.94	39.12	55.30	53.85	39.08	35.81
160× 2	21.58	5.47	10.92	6.36	21.55	13.03	0.93	-8.70	21.43	12.57	32.46	5.90	5.12	4.60	38.02	9.56	41.03	15.08	14.05	20.65
160× 3	12.98	7.80	15.57	15.47	78.00	67.12	4.34	0.49	21.97	13.78	47.85	29.39	19.31	8.29	108.86	107.49	83.79	78.23	64.51	50.88

Conclusions:

It can be concluded that, high positive heterosis for grain yield and its components was found for more than half of the hybrids studied. However, these results indicated that these crosses could be selected and used in breeding programs for improving these traits. The analysis of variance for combining ability revealed that both general combining ability (GCA) and specific combining ability (SCA) variances were highly significant for characters studied indicating importance of additive as well as non- additive types of gene action in controlling these traits. Moreover, variances due to SCA were higher in magnitude than GCA for the yield and yield components except cob diameter, number of row/cob, number of kernels/row and harvest index.

REFERENCES

Ahmed, F.E. and H.A. Elhag, 1999. Effect of watering intervals on yield and yield components of two maize (*Zea mays* L.) cultivars grown in summer and winter. *U. of K. J. Agric Sci.,* 7(1): 20-32.

Beck, D.L., S.K. Vaal and J. Carossa, 1990. Heterosis and combing ability of cimmyt, tropical early and intermediate maturity maize (Zea mays L.) germplasm –maydica, 35: 279-285.

Betran, F.J., J.M. Ribaut, D. Beek and D. Gonzalez de Leon, 2003. Genetic diversity, specific combining ability and heterosis in tropical maize under stress and nonstress environments. *Crop Sci.,* 43: 797-806.

Dehghanapour, Z., B. Ehdaie, M. Moghaddam, B. Griffing and B. Hayman, 1997. Diallel analysis of agronomic characters in white endosperm corn. *J. Genet. and Breed.,* 50(4): 3757-365.

Dehghanapour, Z., B. Ehdaie, M. Moghaddam, B. Griffing and B. Hayman, 1997. Diallel analysis of agronomic characters in white endosperm corn. *J. Genet. and Breed.,* 50(4): 3757-365.

FAO statistics, 2006: www.fao.org.

Gissa, D.W., H. Zelleke, M.T. Labuschagne, T. Hussien and H. Singh, 2007. Heterosis and combining ability for grain yield and its components in selected maize inbred lines. South African Journal of Plant and Soil, 24: 133-137.

GOMEZ, K.A., A.A. GOMEZ, 1984. Statistical Procedures for Agricultural Research. John Willey and Sons, New York. GOMEZ K.A., A.A. GOMEZ, 1984 Statistical Procedures for Agricultural Research. John Willey and Sons, New York.

Gomez, K.A. and A.A. Gomez, 1984. *Statistical Procedures for Agricultural Research*. 2nd. John Willey and Sons (ed). New York, USA.

Hallauer, A.R. and J.B. Miranda, 1988. Quantitative Genetics in Maize Breeding. Iowa State University Press, USA. 468 pp.

Ogunbodede, B.A., S.R. Ajibade and S.A. Olakojo, 2000. Heterosis and combining ability for yield and yield related characters in some Nigerian local varieties of maize (*Zea mays*). Moor J. of Agricultural Research 1: 37-43.

Ismail, A.A., 2004. Estimation of General and Specific Combing Abilities of Some Maize Inbred Lines. PhD. (Agric) thesis faculty of Agriculture University of Khartoum, Sudan.

Kempthorne, O., 1957. An introduction to genetic statistics. Jonh Wiley and Sons, New York: 468-472.

Koutsika-Sotiriou, M., 1999. Hybrid seed production in maize. *In* Basra AS (Ed.), Heterosis and Hybrid Seed Production in Agronomic Crops. Food Products Press, New York, pp: 25-64.

Mathur, R.K., S.K. Chunilal, Bhatnagar and V. Singh, 1998. Combing ability for yield phonological and ear characters in white seeded maize Indian Journal of genetics and Plant breeding, 58(2): 177-182.

Mohammed, A. A., 1993. Effect of nitrogen fertilization levels on the performance and combining ability of maize hybrids (*Zea mays* L.). *Ann. Agric. Sci.*, 38(2): 531-549.

Nour, A.M., I. Nur Eldin and M. Dafalla, 1997. Crop development and improvement. Annual report of maize research program. Medani- Sudan.

Paul, K.K. and S.C. Debnath, 1999. heterosis and combing ability for grain yield and its components in maize (zea mays L.), Bangladesh, J. agric, 24: 61-68.

Rokadia, P. and S.K. Kaushik, 2008. Exploitation of combing ability for heterosis in maize (Zea mays L.): In: Pixely, K and S.H. Zhang (ed). Prol.9 th Asian Rey, maize workshop. Beijing, China, September 5-9, pp: 89-91.

Roy, N.C., S.U. Ahamed, S.A. Hussain and M.M. Hogue, 1998. Heterosis and combing ability analysis in maize (Zea maysL.).Banalgdesh. J.PL. Breed. Genet., 11: 35-41.

Salasya, B.D.S., W. Mwangi, H. Verkuijl, M.A. Odendo and J.O. Odenya, 1998. An assessment of the adoption of seed and fertilizer package and role of credit in smallholder maize production in Kakamega and Vihiga districts, Kenya. Mexico, D.F. CIMMYT and KARI

Sedhom, S.A., 1994. Estimation of general and specific combining ability in maize under different planting dates. *Ann. Agric. Sci.*, 28(1): 25-30.

Sharief, AE., SE. El-Kalla, HE. Gado, HAE. Abo-Yousef, 2009. Heterosis in yellow maize. Aust J Crop Sci., 3: 146-154.

Sharma, S., MS. Narwal, R. Kumar, S. Dass, 2004. Line x tester analysis in maize (*Zea mays* L.). Forage Res., 30: 28-30.

Singh, R.K. and B.D. Chaudhary, 1979. Biometrical Methods in Quantitative Genetic Analysis. Kalyani publishers, New Delhi.

Sprague, GF., LA. Tatum, 1942. General versus specific combining ability in single crosses of corn. J Amer Soci Agron., 34: 923-928.

Tollenaar, M., A. Ahmanzadeh and E.A. Lee, 2004. Physiological basis of heterosis for grain yield in maize. Crop Science, 44: 2086-2094.

Young, J. and S.S. Virmani, 1990. Heterosis in rice over environments. Euphytica, 51: 87-93.