http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 12 (5): 433-438, 2009
ISSN 1028-8880

Combining Ability and Heterosis for Some Agronomic Traits in Crosses of Maize

[1]M.A. Abdel-Moneam, [1]A.N. Attia, [2]M.I. EL-Emery and [3]E.A. Fayed
[1]Department of Agronomy, Faculty of Agriculture, Mansoura University, Egypt
[2]Under Secretary of Ministry of Agriculture for Seed Production, Egypt
[3]Department of Seed Technology Research, Agriculture Research Center, Egypt

Abstract: In 2007, five maize inbred lines were crossed in all possible combinations without reciprocals by using a half diallel crosses mating design to obtain 10 single cross. Inbred parents and their F_1 single crosses were evaluated through 2008 season to evaluate the role of general and specific combining ability and heterosis for some agronomic traits. Results indicated that mean squares of genotypes were highly significant for all studied traits i.e., ear diameter, ear length, number of kernels/row, 100-kernel weight, ear yield per plant, grain yield per plant and shelling percentage. General Combining Ability (GCA) and Specific Combining Ability (SCA) mean squares were highly significant for all studied traits. The GCA/SCA ratio was less than unity for all studied traits; this means that these traits are predominantly controlled by non-additive gene action. Significant positive GCA effects were found for all studied traits. Based on GCA estimates, it could be concluded that the best combiners were Rg5 and Rg8 inbred lines for most of studied traits. This result indicated that these inbred lines could be considered as good combiners for improving these traits. Significant positive SCA effects were found for all studied traits. Based on SCA effects, it could be concluded that the best crosses for ear diameter and 100-kernels weigh was G507A×G516; for ear length was G516×Rg8; for kernels number/row was G516×G278; for ear yield/plant, grain yield/plant and Shelling percentage was G278×Rg5. These crosses could be selected and used in breeding programs for improving these traits. Results showed positive significant heterosis values for all studied traits. The best crosses over both their mid-parents and better-parents for ear diameter and 100-kernel weigh was G507A×G516; for ear length and kernels number/row was G516×G278; for ear yield/plant and grain yield/plant was G278×Rg8 and for Shelling percentage was G278×Rg5.

Key words: Half diallel crosses, heterosis, General combining ability, specific combining ability

INTRODUCTION

Maize is one of the most important cereal crops. For many years, it is used as food for human and different animals. Therefore, corn breeders give great and continuous efforts to improve and increase the yielding ability of this crop. In the year 1763, Koelreituer and Sprangel (Allard, 1960) were the first research workers who observed that hybrids were often possessed the most striking and unusual vigor. Since that time, many research workers generally and corn breeders specially started a new area of plant breeding to benefit from this phenomena, which is now known as heterosis. Hybridization in corn started as early as the year 1908 by the work of East (1908) and Shull (1909), who clearly indicated that hybridization is the opposite of inbreeding. Mosa (1996) evaluated 10 inbred lines of maize and 45 F1 hybrids among them and revealed that both general and specific combining abilities were significant for ear length, ear diameter, number of kernels/row and grain yield. Amer *et al.* (1998) revealed that the GCA and SCA mean squares were highly significant for all studied traits i.e., grain yield, ear length, ear diameter and number of kernels/row. Aly (1999) indicated that both GCA and SCA variances were significant for grain yield, ear diameter, ear length and number of kernels/row for the two years and from the combined data over both years. Choukan (1999) indicated that general combining ability effects were highly significant for grain yield and 1000 grains weight. He also added that specific combining ability was significant for grain yield and he concluded that both additive and non-additive effects were found to be important in genetical control of the previous traits. Soliman and Sadek (1999) observed that five inbred lines exhibited the highest positive and significant GCA effects for grain yield trait. El-Absawy (2002) cleared that GCA mean squares were significant for grain yield per plant, ear diameter and 100 grain weight and also added that the

Corresponding Author: M.A. Abdel-Moneam, Department of Agronomy, Faculty of Agriculture, Mansoura University, Egypt

mean squares of SCA were significant for ear diameter and 100 grain weight. El-Shouny *et al.* (2003) reported that the GCA and SCA mean squares were highly significant for ear diameter, number of kernels/row and grain yield/plant. Meanwhile, the GCA/SCA ratio was larger than unity for all the studied traits except grain yield/plant, indicating that the GCA were important than SCA in the inheritance of these traits. EL-Moselhy (2005) found that the mean squares for General Combining Ability (GCA) Specific Combining Ability (SCA)were highly significant for most of yield and yield components traits under different drought stress and non-stress treatments in both seasons. Barakat and Osman (2008) indicated that the tested inbred lines and testers exhibited significant GCA effects vary greatly according to the studied traits. The variance magnitude due to GCA for tested and tester lines was higher than that due to SCA for all studied traits, this indicates that additive genetic variance was the major source of variation responsible for the inheritance of these traits.

Amer *et al.* (1998) evaluated a half-diallel set of ten inbred lines of maize and showed that heterosis as average percentage from mid-parents were 259.76, 48.81, 27.72 and 59.06% for grain yield, ear length, ear diameter and number of kernels/row, respectively. Yassien (1999) estimated heterosis in three crosses of maize and found that the highest values of heterotic effects were 61.15 and 57.5% for grain yield/plant relative to mid and higher parents, respectively. El-Aal (2002) evaluated a set of half-diallel crosses among eight inbred lines and the six populations of each cross and revealed that heterosis values relative to the better parent were negative and significant for ear length, ear diameter, number of kernels/row and grain yield/plant. Venugopal *et al.* (2002) evaluated a set of diallel crosses among ten parental lines of maize for the extent of heterosis over better parent and standard check for yield and its component traits. Their results indicated the presence of pronounced hybrid vigor for all studied traits. Forty two out of forty five hybrids exhibited significant positive heterosis with a maximum of 136.67%. Mosa (2003) evaluated half-diallel crosses between eight inbred lines of maize for the presence of heterotic effect for grain yield under two locations and revealed that heterosis percentage relative to mid parents and better parent were highly significant and positive. The values of heterosis relative to mid-parents ranged from 58.33 to 751.98% for grain yield. While, the values relative to better parent ranged from 24.08 to 709.88% for the same trait. Alvi *et al.* (2003) evaluated eight F_1 hybrids of maize and cleared that the F_1 hybrids exceeded their parents. The obtained values of heterosis ranged from 21.44 and 8.81% to 34.41 and 33.04% for ear length and weight of 1000 kernels, respectively. Shafey *et al.* (2003) studied 28 F1 hybrids of corn and their eight parental inbred lines and he obtained quite large and medium values of heterosis for most. El Maksoud *et al.* (2004) evaluated five inbred lines of maize and 10 F1 hybrids among them in two growing seasons and they revealed that the superior F1 hybrids were: (G2-628×L-8084), (Sd-7×L-7041) and (L-7041×L-8084). El-Gazzar (2004) evaluated 28 fi hybrids of maize and illustrated that the calculated values of heterosis were positive and highly significant for all studied vegetative and yield component traits. Welcker *et al.* (2005) studied the behavior of some genotypes of maize at five environments and obtained highly significant heterosis versus the mid-parents for grain yield with a mean value of 32% EL-Diasty (2007). For yield component traits, the largest amounts of heterosis estimated from the mid-parent and the better parent for ear weight trait which showed 72.38 and 72.33% for the hybrid 4×10, respectively. For ear length. trait, the largest amounts of heterosis were 43.92 and 41.30% for hybrid 2×10 from the mid-parent and the better parent, respectively. For ear diameter trait, the largest amounts of heterosis were 20.87 and 19.70% for the hybrid 3×10 from the mid-parent and the better parent, respectively. For rows No./ear trait, the largest amounts of heterosis were 19.55 and 16.46% for hybrid 3×7 from the mid-parents and the better parent, respectively. For the last trait, 100-kernel weight, the largest amounts of heterosis were 29.89 and 16.51% for hybrids 3×10 and 2×10 from the mid-parent and the better parent, respectively. The objective of this study was to evaluate of combining ability and estimate the heterosis for some agronomic traits in diallel crosses of maize.

MATERIALS AND METHODS

Five white maize inbred lines were used. These inbred lines were: Giza 507 A, Giza 516, Giza 278, Rg 5 and Rg 8. The seeds of all inbred lines were obtained from Maize Research Department, Field Crop Research Institute, Agricultural Research Center (ARC), Ministry of Agriculture and Land Reclamation, Egypt. In 1st May 2007 growing season, the seeds of all parental inbred lines were planted in the Farm of the Agronomy Department, Faculty of Agriculture, Mansoura University. All parental inbred lines were crossed according to a half diallel crosses mating design to obtain 10 single crosses during 2007 season. In 21 April 2008 growing season, all

15 genotypes, which included 5 parental inbred lines and 10 F_1 hybrids were cultivated using the dry methods (Afir). In both seasons, maize crop was preceded by Clover (*Trifolium alexandrinume* L.). The soil was ploughed two times then ridged. Calcium super phosphate (15.5% P_2O_5) was incorporated in the soil during tillage operation at a rate of 150 kg/fed. Nitrogen fertilizer in the form of Urea (46% N) was added at the rate of 120 kg N/fed in two equal doses, the first was after thinning and before the first irrigation and the second before the second irrigation. The first irrigation was applied after 21 days from planting and then at 15 days intervals during the growing seasons. Weeds were controlled by using manual method before irrigation. Plants were thinned later to one plant per hill before the first irrigation, providing a population density of about 24000 plants/fed. Other agricultural practices were carried out as recommended by Ministry of Agriculture and Land Reclamation. The plot size was 10.5 m^2 and each plot consisted of 5 ridges, 3 m long and 70 cm wide. Samples of ten guarded plants were taken at random from middle two rows of each plot to determine the quantitative and qualitative characters.

Studied traits: The following measurements were recorded: ear diameter, ear length, number of kernels/row, 100-kernel weight, ears yield per plant, grain yield per plant and shelling percentage.

Diallel analysis for general and specific combining ability: Ten single crosses comprise a half diallel between 5 inbred parents. Data of all 15 genotypes were analyzed as randomized complete blocks. The sum of squares of genotypes was partitioned to general and specific combining ability following method 2 model 1 (fixed effects) of Griffing (1956) as shown in Table 1.

Table 1: Analysis of variance and expected mean squares for combining ability analysis

SOV	df	MS	EMS
GCA	P-1	Mg	$\sigma^2_e + (p+2)(1/p-1)\Sigma g^2 i$
SCA	P(P-1)/2	Ms	$\sigma^2_e + 2/p\ (p-1)\Sigma i\ \Sigma j\ S^2_{ij}$
Error	(r-1)(c-1)	Me	σ^2_e

Where, Me: The error mean squares of the main randomized complete block design divided by number of replications (Me = Me/r), P: No. of parents

The relative importance of GCA to SCA was expressed as follows:

$$k^2\,GCA/k^2\,SCA = [(MS_{GCA} - Ms_e)/(P+2)] / (MS_{SCA} - Ms_e)$$

Where:
MS = Mean squares
P = No. of parents
k^2 = The average squares of effects

General combining ability effects for the inbred parents, specific combining ability effects for cross combinations and their respective standard errors were computed using formulae given in Griffing (1956).

RESULTS AND DISCUSSION

Results indicated that mean squares of genotypes were highly significant for all studied traits i.e., ear diameter, ear length, number of kernels/row, 100-kernel weight, ear yield per plant, grain yield per plant and shelling percentage (Table 2). General combining ability mean squares (GCA) were highly significant for all studied traits. Also, mean squares of Specific Combining Ability (SCA) were highly significant for all studied traits. The GCA/SCA ratio was less than unity for all studied traits; this means that these traits are predominantly controlled by non-additive gene action. Similar results were reported by El-Enany (1998), Atta (2001), Hassaballa *et al.* (2002), El-Morshidy *et al.* (2003), EL-Moselhy (2005) and EL-Diasty (2007).

General combining ability effects (g_i): Significant positive GCA effects were found for all studied traits. Based on GCA estimates, it could be concluded that the best combiners for ear diameter and ear length were inbred lines of Rg5 and Rg8; for kernels No./row were G516, G507A and Rg5 inbred lines; for 100-kernels weight were Rg5 and G516 inbred lines; for ear yield/plant was Rg5 inbred line; for grain yield/plant was inbred line Rg5 and for Shelling percentage was G507A inbred line. These results indicated that these inbred could be considered as good combiners for improving these traits (Table 3).

Table 2: Mean squares from analysis of variance, for General Combining Ability (GCA) and Specific Combining Ability (SCA) of all studied traits of maize

SOV	df	Ear diameter	Ear length	Kernels/row	100-kernels weight	Ear yield/plant	Grain yield/plant	Shelling (%)
Genotypes	14	4.38**	90.42**	314.90**	115.820**	12207.71**	9473.29**	305.91**
GCA	4	2.56**	27.12**	244.76**	41.180**	5749.21**	3236.62**	126.67**
SCA	10	5.12**	115.74**	342.96**	145.670**	14791.12**	11967.97**	377.60**
Error	42	0.02	1.11**	4.93	0.593	30.69	45.94	21.57
SCA/GCA	-	0.07	0.03	0.10	0.040	0.06	0.04	0.04

*, **Significant at level of probability 0.05 and 0.01, respectively

Table 3: Estimates of general combining ability effects (g_i) for inbred parents for all studied traits of maize

	Traits						
Crosses	Ear diameter	Ear length	Kernels/row	100-kernel weight	Ear yield/plant	Grain yield/plant	Shelling (%)
P1(G507A)	-0.231**	-0.431	2.150**	-1.378**	-9.017**	-7.006**	2.440*
P2(G516)	-0.358**	0.427	2.293**	0.661**	0.323	-0.248	0.233
P3(G278)	0.07	-0.659*	-4.279**	0.197	-9.301**	-5.788**	-3.337**
P4(Rg5)	0.407**	1.526**	1.757**	1.558**	24.674**	18.659**	0.936
P5(Rg8)	0.112*	0.862**	-1.921**	-1.039**	-6.680**	-5.617**	-0.272**
SE (g_i)[1]	0.032	0.178	0.375	0.130	0.936	1.146	0.785
SE (g_i-g_j)[2]	0.045	0.281	0.594	0.205	1.481	1.811	1.241

*, **Significant at level of probability 0.05 and 0.01, respectively, [1]Standard error for an GCA effect, [2]Standard error for the difference between estimates of GCA effects

Table 4: Estimates of specific combining ability effects (s_{ij}) for all F_1 crosses for all studied traits of maize

	Traits						
Crosses	Ear diameter	Ear length	Kernels/row	100-Kernel weight	Ear yield/plant	Grain yield/plant	Shelling (%)
1-G507A×G516	1.111**	3.456**	3.857**	5.992**	40.813**	27.840**	-3.367
2-G507A×G278	0.933**	4.918**	9.679**	0.257*	29.980**	24.260**	5.129*
3-G507A×Rg5	0.271**	0.083	-3.107**	1.370**	-1.144	3.397	1.748
4-G507A×Rg8	0.716**	-0.255	-0.429^{ns}	4.817**	42.709**	37.719**	2.674
5-G516×G278	0.763**	5.060**	10.536**	5.342**	40.415**	39.802**	11.169**
6-G516×Rg5	0.231**	1.750**	7.000**	2.516**	25.636**	20.492**	0.597
7-G516×Rg8	0.918**	5.888**	6.679**	4.278**	50.471**	46.356**	5.735*
8-G278×Rg5	0.320*	3.086**	3.071**	2.120**	54.585**	57.869**	12.402**
9-G278×Rg8	0.615**	3.224**	6.500**	5.167**	39.493**	32.396**	7.664**
10-Rg5×Rg8	0.203*	-0.711**	-2.036	0.241	9.458**	7.763*	0.981
SE sca (ij)[1]	0.071	0.460	0.970	0.340	2.420	2.960	2.030
SE sca (ij-ik)[2]	0.100	0.690	1.540	0.500	3.630	4.440	3.040
SE sca (ij-kl)[3]	0.090	0.630	1.330	0.460	3.300	4.050	2.780

*, **Significant at level of probability 0.05 and 0.01, respectively, [1]Standard error for an SCA effect, [2]Standard error for the difference between two SCA effects for a common parent, [3]Standard error for the difference between two SCA effects for a non-common parent

Table 5: Percentages of heterosis over mid-parents for all studied traits

	Traits						
Crosses	Ear diameter	Ear length	Kernels No./row	100-Kernel weight	Ear yield/plant	Grain yield/plant	Shelling (%)
1-G507A×G516	153.96**	100.85**	51.69**	102.73**	215.52**	222.16**	2.26
2-G507A×G278	105.38**	132.37**	103.97**	47.27**	255.43**	311.42**	23.66**
3-G507A×Rg5	43.10**	23.51**	2.01	34.90**	53.48**	71.86**	9.50**
4-G507A×Rg8	90.06**	37.66**	18.27**	93.90**	226.06**	260.48**	11.39**
5-G516×G278	103.33**	182.66**	172.42**	36.14**	327.29**	464.85**	38.10**
6-G516×Rg5	43.41**	55.05**	57.01**	50.09**	96.91**	118.17**	11.22**
7-G516×Rg8	104.57**	132.30**	75.72**	37.43**	277.711**	349.36**	19.24**
8-G278×Rg5	36.49**	72.64**	59.49**	29.07**	150.14**	219.07**	40.50**
9-G278×Rg8	69.43**	117.80**	113.68**	87.35**	344.29**	479.29**	34.33**
10-Rg5×Rg8	31.11**	18.10**	6.97	31.56**	77.44**	98.82**	12.99**
LSD 5%	0.16	1.06	2.24	0.78	5.58	6.83	4.68
LSD 1%	0.23	1.50	3.17	1.10	7.89	9.65	6.62

*, **Significant at level of probability 0.05 and 0.01, respectively

Specific combining ability effects (S_{ij}): Significant positive SCA effects were found in all studied traits for most crosses (Table 4). Based on SCA effects, it could be concluded that the all crosses showed significant and positive SCA effects for ear diameter. The crosses for ear length and kernels No./row were seven crosses i.e., No. 1, 2, 5, 6, 7, 8 and 9, for 100-kernel weight were all crosses, except cross No. 10; for ear yield/plant and grain yield/plant were all crosses, except cross No. 3 and for shelling percentage were five crosses i.e., No. 2, 5, 7, 8 and 9. These crosses could be selected and used in breeding programs for improving these traits.

Heterosis over mid-parents: Results showed positive significant heterosis values for all studied traits for all crosses except crosses No. 3 and 10 for kernels No./row and cross No. 1 for shelling percentage (Table 5). The highest crosses over their mid-parents for ear diameter and 100-kernel weight was cross No. 1; for ear length and kernels No./row was cross No. 5; for ear yield/plant and grain yield/plant was cross No. 9 and for shelling percentage was cross No. 5.

Heterosis over better-parents: Results showed positive significant heterosis values over better-parents in all

Table 6: Percentages of heterosis over better-parents for all studied traits

	Traits						
Crosses	Ear diameter	Ear length	Kernels No./row	100-Kernel weight	Ear yield/plant	Grain yield/plant	Shelling (%)
1-G507A×G516	136.61**	79.41**	29.75**	92.44**	203.99**	194.63**	-3.10
2-G507A×G278	74.14**	83.00**	27.27**	33.31**	164.73**	58.67**	3.06
3-G507A×Rg5	3.41	1.39	-0.78	6.38**	7.18**	23.71**	4.18
4-G507A×Rg8	57.14**	32.20**	1.65	91.11**	194.17**	205.44**	3.83
5-G516×G278	62.74**	144.66**	83.72**	79.55**	226.51**	293.47**	20.49**
6-G516×Rg5	-0.73**	16.67**	31.25**	19.47**	34.65**	48.85**	10.75**
7-G516×Rg8	60.00**	115.38**	74.71**	82.51**	252.74**	312.92**	17.18**
8-G278×Rg5	11.92**	18.18**	-1.56	17.16**	49.36**	82.4**	22.14**
9-G278×Rg8	64.29**	76.92**	43.68**	67.40**	257.37**	325.57**	18.99**
10-Rg5×Rg8	10.22	-6.06	-10.16	2.73	17.03**	29.77**	10.58**
LSD 5%	0.18	1.32	2.59	1.00	6.44	7.88	5.40
LSD 1%	0.26	1.73	3.66	1.27	9.11	11.15	7.64

*, **Significant at level of probability 0.05 and 0.01, respectively

studied traits for most crosses. The highest crosses over their better-parents for ear diameter and 100-kernel weight was cross No. 1; for ear length, kernels No./row and shelling percentage was cross No. 5; for ear yield/plant and grain yield/plant was cross No. 9 (Table 6).

REFERENCES

Allard, R.W., 1960. Principles of Plant Breeding. 1st Edn., John Wiley and Sons, Inc., New York.

Alvi, M.B., M. Rafique, M.S. Tariq, A. Hussain, T. Mahmood and M. Sarwar, 2003. Hybrid vigor of some quantitative characters in maize (*Zea mays* L.). Pak. J. Biol. Sci., 6: 139-141.

Aly, R.S.H., 1999. Genetical studies for some agronomical and technological characters of maize (*Zea mays* L.). M.Sc. Thesis, Faculty of Agriculture, Kafr El-Sheikh, Tanta University, Egypt.

Amer, E.A., A.A. El-Shenawy and F.A. El-Zeir, 1998. Diallel analysis for ten inbred lines of maize. Egypt. J. Appl. Sci., 13: 79-91.

Atta, M.M.M., 2001. A study of combining ability and heterosis for drought tolerance in some maize populations. Ph.D Thesis, Agron. Department, Faculty of Agriculture, Cairo University.

Barakat, A.A. and M.M.A. Osman, 2008. Gene action and combining ability estimates for some white promising maize inbred lines by top cross system. J. Agric. Sci., Mansoura Univ., 33: 6995-7009.

Choukan, R., 1999. General and specific combining ability often maize inbred lines for different traits in diallel cross. Seed Plant, 15: 280-295.

East, E.M., 1908. Inbreeding in corn. Rept. Connecticut Agric. Exp. Sta., 1907: 419-428.

El-Aal, A.M.AA., 2002. Studies on mode of downy mildew disease resistance of some maize inbred lines and their hybrid combinations. Ph.D Thesis, Faculty of Agriculture, Cairo University, Egypt.

El-Absawy, E.A., 2002. Estimation of combining abilities and heterotic effects in maize. Minufiya J. Agric. Res., 27: 1363-1373.

El-Diasty, M.Z., 2007. Genetic evaluation of hybrids in relation to their parents in intraspecific crosses in maize. M.Sc. Thesis, Faculty. Agriculture, Mansoura University, Egypt.

El-Enany, A.F.M., 1998. Breeding studies on maize for stress conditions. Ph.D Thesis, Agronomy Department, Faculty of Agriculture, Ain Shams University.

El-Gazzar, A.I., 2004. Genetic variability in some maize inbred lines. M.Sc. Thesis, Faculty of Agriculture, Mansoura University, Egypt.

El-Maksoud, A.M.M., A.M. El-Adl, Z.M. El-Diasty, A.A. Galal and R.S. Hassanin, 2004. Estimates of combining ability and heterosis in some maize inbred lines for the important traits. J. Agric. Sci. Mansoura Univ., 29: 133-143.

El-Morshidy, M.A., E.A. Hassaballa, Sh.F. Aboul-Saad and M.A. Ahmed, 2003. Selection for drought tolerance in maize (*Zea mays* L.). Proceedings of the 3rd Scientific Conference of Agriculture Science, Assiut, Oct., 2003, pp: 173-191.

El-Moselhy, A.A., 2005. Comparison of the response of some different maize genotypes to cultivation under moisture stress conditions. Ph.D Thesis, Agronomy Department, Faculty of Agriculture, Mansoura University, Egypt.

El-Shouny, K.A., Olfat, H. EL-Bagoury, H.Y. El-Sherbieny and S.A. Al-Ahmed, 2003. Combining ability estimates for yield and its components in yellow maize (*Zea mays* L.) under two plant densities. Egypt. J. Plant Breed, 7: 399-417.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci., 9: 463-493.

Hassaballa, E.A., M.A. El-Morshidy, Sh. F. Aboul-Saad and M.A. Ahmed, 2002. Combining ability and type of gene action in maize under favorable and water stress environments. The 3rd Scientific Conference of Agriculture Science, Assiut, Oct., 2002, pp: 151-171.

Mosa, H.E., 1996. Studies on corn breeding. M.Sc. Thesis, Faculty of Agriculture, Kafr, El-Sheikh, Tanta University, Egypt.

Mosa, H.E., 2003. Heterosis and combining ability in maize (*Zea mays* L.). Minufiya, J. Agric. Res., 28: 1375-1386.

Shafey, S.A., H.E. Yassien, I.E.M.A. El-Beially and O.A.M. GadOAlla, 2003. Estimates of combining ability and heterosis effects for growth, earliness and yield in maize (*Zea mays* L.). Egypt. J. Agric. Sci., Mansoura Univ., 28: 55-67.

Shull, G.H., 1909. A pure line method of corn breeding. Rept. Am. Breeders Assoc., 4: 296-301.

Soliman, F.H.S. and S.E. Sadek, 1999. Combining ability of new maize inbred lines and its utilization in the Egyptian hybrid program. Bull. Fac. Agric., Cairo Univ., 50: 1-20.

Venugopal, M., N.A. Ansari and K.G.K. Murthy, 2002. Heterosis for yield and its components characters in maize (*Zea mays* L.). Res. Crops, 3: 72-74.

Welcker, C., C.B. Andreau, C.D. Leon, S.N. Parentoni and J. Bernal *et al*., 2005. Heterosis and combining ability for maize adaptation to tropical acid soils. Crop Sci., 45: 2405-2413.

Yassien, H.E., 1999. Genetic analysis in three yellow maize (*Zea mays* L.) crosses. J. Agric. Sci. Mansoura Univ., 24: 5319-5331.