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HETEROSIS AND COMBINING ABILITY IN DIALLEL CROSSES AMONG SOME MAIZE POPULATIONS UNDER LOW SOIL-N CONDITIONS

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ABSTRACT

The objectives of this study were to determine maize populations and population crosses of high tolerance to low-N and to study heterosis and combining ability of diallel population crosses under low- and high-N conditions. In 2002 season, nine maize open-pollinated populations were crossed in a diallel system (excluding reciprocals). In 2003 season, the 9 parental populations and resulting 36 population crosses were evaluated under high- and low-N conditions. Significant mean squares were existed among studied genotypes and N levels for all studied traits, except for ears/plant. Estimates of heterobeltiosis for grain yield and its components increased under low- than under high-N conditions. Ten out of 36 population crosses showed significant positive heterobeltiosis for grain yield under low-N. The highest positive heterobeltiosis estimates for grain yield and nitrogen use efficiency(NUE) resulted from crossing between parent populations of different origins. The magnitude of GCA variance was greater than that of SCA variance for 6 traits including grain yield and NUE under both high- and low-N, indicating that additive was more important than non-additive genetic variance. Tuxpeno, Giza-2, DTP-1 and Tep-5 were the best populations in *per se* performance and GCA effects for grain yield and NUE and could be considered as suitable materials for improving traits related to low-N tolerance in maize selection programs. Superiority of population crosses in their *per se* performance, heterobeltiosis and SCA effects, were shown by the crosses Tep-5 X BS-26, C-87 X Tuxpeno , AED X BS-11 Giza-2 X Tep-5, Giza-2 X BS-26, C-87 X Tep-5 and Giza-2 X DTP-1 in descending order. Such population crosses could be recommended for a heterosis breeding program to isolate inbred lines and develop single cross hybrids of high tolerance to low- N stress conditions.

Keywords: Maize, Diallel, Population crosses, Low-N tolerance, Nitrogen use efficifency; NUE, Heterossis, Combining ability.

INTRODUCTION

Nitrogen is the most important nutritive element for the worldwide production of cereals (wheat, maize, rice, barley and sorghum). A considerable portion of fertilizer N is lost through gaseous plant emissions, soil dentrification, surface runoff, ammonium volatilization and leaching (Akintoye *et al.*, 1999 and Raun and Johnson, 1999). The affordability of N in the developed countries has led to its misuse and over application (Raun and Johnson, 1999) and created growing environmental concerns from increased nitrate leaching that may lead to ground water contamination. In contrast, the rates of N fertilizers in many developing countries such as Egypt are considerably low because of the limited access to fertilizers and low purchasing power of small farmers. Therefore, farmers cannot increase yield, as the availability of N fertilizers in crop production is often limited (FAO, 2000).

Nitrogen use efficiency (NUE), is defined as the ability of a genotype to produce superior grain yield under low soil N conditions in comparison with other genotypes (Grohan, 1984). Genotypic differences in NUE among maize genotypes have been reported by several authors (Bruetsch and Estes 1976, Chevalier and Scharders 1977, Moll *et al.*, 1982, Hageman and Below 1984, Van and Smith 1996, El-Moselhy 2000, Omoigui *et al.* 2006, and Al-Naggar *et al.* 2008). Therefore, NUE trait could be improved *via* conventional breeding methods.

To start a new plant breeding programme, there is a need to decide what parents will be used and determine the appropriate breeding procedure for improving a given character. Diallel crossing system is the best way to provide such information. Sprague and Tatum (1942), used the diallel cross design to determine the relative importance of general (GCA) and specific (SCA)combining abilities for the lines included in each set of crosses. They defined GCA as the average performance of a line in hybrid combinations, while SCA is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Also they interpreted GCA as an indication of genes having largely additive effects, and SCA as indication of genes having dominance and epistatic effects.

Both GCA and SCA variances were important under high- and low-N conditions. Rizzi *et al.* (1993), reported that GCA for grain yield under low- and high-N was significant. Moreover, El-Moselhy (2000) found that SCA appeared to be responsible for variation in grain yield and NUE under low-N. Chen *et al.* (2002), reported significant additive as well as dominance variance for grain yield under low-N. Meseka *et al.* (2006), observed that non-additive was slightly higher than additive gene action for grain yield under low-N. They reported an average heterosis of 129% for grain yield under low-N and 114 % under high-N.

The objectives of the present investigation were: (1) to identify the maize populations and population crosses of high tolerance to low-N and (2) to study heterosis and combining ability in diallel crosses among nine populations under low- and high-N conditions.

MATERIALS AND METHODS

In 2002 season, nine maize open-pollinated populations viz, Giza-2 , C- 87, DTP-1 , DTP-2 , Tepalcinco (Tep-5), American Early Dent (AED), Tuxpeno, BS-11 and BS- 26 (Table 1) were grown at Experimental Station of Faculty of Agriculture, Cairo University, Giza and all possible crosses (excluding reciprocals) were made among these populations. To insure a good sampling , a minimum of 40 plants were used from each population for crossing. Seeds harvested from female parents of each cross were then blended, and 36 inter- population crosses were produced.

In 2003 season, the 9 parental populations and 36 population crosses (a total of 45 genotypes) were field evaluated at the Experimental Station of Fac. of Agric., Cairo Univ., Giza, Egypt under two soil-N treatments; high-N (applying 120 Kg N / feddan) and low-N (non–applying any nitrogen fertilization). A split- plot design with a randomized complete block arrangement was used with 3 replications. The two N treatments were allotted to the main plots and the genotypes were devoted to sub-plots. Each sub plot consists of one row of 5 length and 0.7 m width (3.5 m^2). Each main plot was surrounded with a wide ridge (1.5 m) to avoid interference of the two N treatments. Sowing date was on May 25 in 2003 season. Seeds over sown in hills at 25 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill to reach a plant density of 24.000 plants/fed (one feddan = 4200m^2). Amonium nitrate (33.5 % N) at the rate of 120 Kg N /fed was added only for high-N treatment in two equal doses before the first and second irrigations. No any organic fertilizer was added to the experiment. The pervious crop was faba bean. The other cultural practices were carried out as recommended by ARC for the region. Before N application, 30 ramdom samples (taken from 0 to 15 cm depth) were collected in each replication of main plots and composited to determine soil-N concentration. The amount of available soil-nitrogen in Kg/fed was then calculated and found to be 50.1 kg N/fed under low-N and therefore 170.1 kg N/fed under high-N environments. Available nitrogen in the soil was therefore 2.19 g/plant under low-N and 7.44 g /plant under high-N. The soil of the experimental site was clayey loam and the pH was 7.8.

Table 1. Origin and genetic nature of maize populations used in the present study

Population	Origin	Genetic nature
1- Giza -2	ARC- Egypt	Local cultivar (composite)
2- C- 87	Cairo Univ., Egypt	Open-pollinated population (composite)
3- DTP-1	CIMMYT, Mexico	Drought tolerant open- pollinated population
4- DTP-2	CIMMYT, Mexico	Drought tolerant open- pollinated population
5- Tep-5	CIMMYT, Mexico	Open- pollinated population
6- AED	ARC, Egypt	Local old open-pollinated cultivar
7- Tuxpeno	CIMMYT, Mexico	Open-pollinated population
8- BS -11	Iowa State Univ., USA	Open-pollinated population
9- BS-26	Iowa State Univ., USA	Open-pollinated population

ARC= Agricultural Research Center
CIMMYT = International Center for Maize and Wheat Improvement

Data on number of days from planting to 50 % anthesis and to 50% silking and anthesis- silking interval (ASI) in days were recorded on a plot basis. At harvest. 5 random guarded plants from each plot were used to record plant height (cm), number of ears/plant and grain yield/plant (g). Rows/ear, number of kernels/row and 100-kernel weight were determined on 5 random ears from each plot. The grain yield/plant was adjusted on the basis of 15.5 % grain moisture content. Nitrogen use efficiency (NUE) in g/g was determined by using the following equation: NUE = grain yield per plant (g) / available soil N per plant (g) .

The ordinary analysis of variance of a split-plot design was done according to Steel and Torrie (1980). Heterobeltiosis (%) was computed as a percentage of F_1 superiority over the better parent. General (GCA) and specific (SCA) combining abilities were estimated according to method 2 , model 1 (fixed model) of Griffing (1956) for each N treatment.

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance (Table 2) showed that highly significant differences existed among studied genotypes for all studied traits, except for ears/plant. Highly significant differences were also noted among parents and among crosses for all studied traits, except for ears/plant. Significant or highly significant mean squares due to parents vs. crosses (heterosis) existed for five out of ten traits, namely rows/ear, kernels/row, 100-kernel weight, grain yield/plant and NUE. Significant or highly significant mean squares were also existed among N levels for all studied traits, except for ears / plant.

Mean squares due to genotypes X N levels and parents X N levels interactions were highly significant for all studied traits, except ears/plant and plant height. Also, highly significant mean squares due to crosses X N levels were existed for all studied traits, except for 50 % silking , ears /plant and plant height. These results indicated that genotypes, parents and crosses behaved differently under different levels of soil nitrogen for most studied traits. A similar conclusion was reported by Tollenaar *et al.* (1995), Kling *et al.* (1996), Sallah *et al.* (1996), Van and Smith (1996), Presterl *et al.*, (1997), Akintoye *et al.* (1999), El-Moselhy (2000), Chen *et al.*, (2002), Machado *et al.*, (2002), Zaidi *et al.*, (2003), Monneveux *et al.* (2005), Azeez *et al.*, (2006), Meseka *et al.*, (2006), Ferro *et al.* (2007), Zhang *et al.*, (2007) and Al -Naggar *et al.*, (2008).

Mean performance

Summary of mean performances of parental populations and their diallel crosses subjected to high- and low-N environments is presented in Table 3. Mean grain yield/ plant was significantly decreased due to low-N by 46.72 and 41.18 % for parental populations and F_1 crosses, respectively. Under low- N, grain yield/plant ranged from 74.13 (C-87) to 143.13 g/plant (Tuxpeno)for parental populations and from 78.80 (C-87 x DTP-2) to 167.20 g/plant (C-87 x Tuxpeno) for crosses. The significant reduction in grain yield/plant due to soil nitrogen deficiency could be attributed mainly to reduction in kernels/row and 100–kernel weight and to a less extent to rows/ear i.e to its main components.

Reduction due to N-stress was 37.25 and 30.63 % for kernels/row, 35.41 and 29.07 % for 100- kernel weight and 10.85 and 9.75 % for rows/ear in the parental populations and their diallel crosses, respectively. In both parents and F_1 crosses, reduction in kernels/ row and 100–kernel weight due to N-stress was more pronounced than reduction in rows/ear and ears/plant, indicating that the two yield components, i.e. kernel number and kernel weight were the most important contributors to grain yield.

Low-N stress caused delay in 50% anthesis by 2.67 (4.59%) and 2.54 days (4.35 %) and in 50% silking by 4.0 (6.49 %) and 3.34 days (5.34 %) for parents and crosses, respectively . Moreover, low-N stress caused an elongation of ASI by 1.34 (37.11 %) and 0.78 day (19.95%), respectively.

Table 2. Mean squares of all studied traits for parental populations and their diallel crosses evaluated under two N-levels, 2003 season.

S.O.V	d.f.	Mean squares									
		50% Anthesis	50% Silking	ASI	Ears /plant	Plant hieght	Rows /ear	Kernels /row	100-kernel weight	Grain yield /plant	NUE
Replications	2	9.644	19.293	1.781	0.015	406.826	0.706	38.361	1202.076	1601.699	364.065
Nitrogen levels (N)	1	445.959*	811.200**	53.333**	0.214	57670.059**	152.175**	11210.756**	9742.814*	492834.164**	45964.712**
Error (a)	2	14.326	13.144	0.033	0.018	291.804	1.289	33.929	157.883	2036.052	390.553
Genotypes (G)	44	10.277**	11.040**	2.832**	0.006	282.487**	2.002**	13.201**	28.359**	803.999**	144.716**
Parents (P)	8	16.421**	13.583**	1.713**	0.008	379.917**	1.928**	15.386**	18.816**	672.261**	126.036**
Crosses (C)	35	8.947**	10.520**	3.168**	0.005	265.284**	1.649**	12.587**	30.366**	832.538**	146.755**
P vs.C	1	7.668	8.892	0.033	0.001	105.157	14.934**	17.202*	34.454**	859.047**	222.796**
G X N	44	5.467**	4.185**	1.864**	0.005	118.794	1.064**	15.883**	26.465**	731.453**	140.276**
P X N	8	9.875**	9.250**	2.833**	0.008	100.537	0.714**	23.239**	20.442**	690.419**	127.000**
C X N	35	4.611**	3.010	1.6**	0.005	116.335	1.170**	11.917**	26.417**	718.345**	139.777**
P vs.C X N	1	0.157	4.800	3.333*	0.001	350.924	0.129	95.826**	76.321**	1518.482**	263.194**
Error (b)	176	2.879	2.544	0.506	0.006	92.106	0.258	4.157	3.868	119.163	12.168

*and** indicate significant and highly significant at 0.05 and 0.01 levels of probability, respectively.

Table 3. Summary of means averaged across populations and F_1 crosses as well as ranges under high- and low-N conditions, in 2003 season.

	Parental populations			F_1 population crosses		
Traits	Environment	Average	Range	Average	Range	LSD $_{.05}$
Grain Yield	High -N	203.21	191.33 - 213.07	201.75	186.53- 215.17	* N=23.62
/ plant (g)	Low -N	108.28	74.13- 143.13	118.67	78.8- 167.20	G=12.35
	Red.%	46.72	28.56- 63.58	41.18	21.03- 62.77	GxN=17.46
Kernels/ row	High -N	40.99	39.07- 42.87	40.13	36.07- 43.20	N=3.06
	Low -N	25.72	20.93- 23.87	27.84	23.2- 34.07	G=2.31
	Red.%	37.25	25.87- 49.60	30.63	16.91- 39.60	GxN=3.27
100-Kernel	High -N	39.93	36.23- 42.33	39.49	36.20- 43.60	N=2.07
wt.(g)	Low -N	25.79	23.5- 32.77	28.01	24.70- 34.87	G=2.23
	Red.%	35.41	16.91- 41.44	29.07	9.45- 43.26	GxN=3.16
Rows/ear	High -N	14.65	13.63- 16.00	15.18	14.13-16.03	N=0.60
	Low -N	13.06	11.53- 13.73	13.70	12.53- 15.07	G=0.57
	Red.%	10.85	6.48- 20.00	9.75	0.84- 21.95	GxN=0.82
Ears/plant	High -N	1.07	1.00- 1.20	1.06	1.00- 1.20	n.s
	Low -N	1.00	1.00- 1.00	1.00	1.00- 1.00	n.s
	Red.%	6.25	0.00- 16.67	5.09	0.00- 16.67	n.s
Plant height	High -N	211.04	199.67- 221.00	208.81	190.67- 225	N=8.95
(cm)	Low -N	175.74	162.67- 191.33	181.09	165.00- 195.33	G=10.86
	Red.%	16.73	10.9- 20.56	13.27	5.97-21.47	GxN=n.s
50% Anthesis (days)	High -N	58.07	55- 61	58.56	56- 61	N=1.98
	Low -N	60.74	56.67- 62.67	61.10	58.33- 65.33	G=1.92
	Increase%	4.59	1.64- 10.65	4.35	2.22-10.47	GxN=2.72
50%Silking (days)	High -N	61.67	58- 64	62.45	59- 66	N=1.89
	Low -N	65.67	62- 68	65.79	63.67- 69.00	G=1.8
	Increase%	6.49	6.42- 12.64	5.34	0.53- 9.60	GxN=2.55
ASI (days)	High -N	3.59	2.33- 4.67	3.90	3.00- 5.33	N=0.95
	Low -N	4.93	3.33- 6.00	4.68	3.00- 6.00	G=0.80
	Increase%	37.11	7.14- 157.14	19.95	25- 100	GxN=1.14
NUE (g/g)	High -N	27.23	25.64- 28.55	27.03	25.00- 28.83	N=10.37
	Low -N	49.38	33.8- 65.27	54.12	40.22- 76.24	G=3.94
	Increase%	81.33	23.94- 143.09	100.18	26.68- 162.90	GxN=5.59

* Where, N and G are nitrogen levels and genotypes, respectively, ns = non-significant and reduction (Red.) or increase % = 100 [(high-N) – (low-N)] / high-N

It is worthy to note that, NUE increased significantly due to low-N stress by 81.33 % (parents) and 100.18 % (F_1 crosses, Table 3). This is logic, since calculating the values of NUE was based on available soil nitrogen, which was much lower under low-N stress than under high-N conditions. In this aspect, Anderson *et al.* (1984) and Pandey *et al.* (2001), reported that nitrogen use efficiency parameters increased as N rate decreased. It is worthy to note that increases in NUE due to low-N stress were greatly higher in crosses than in their parental populations .

In general, reduction due to N-stress was greater in parental populations than in their F_1 crosses, indicating that F_1 crosses might accord higher tolerance to low-N stress than their parental populations for studied traits. Sinclair and Horie (1989) and Muchow and Sinclair (1994) found that low-N limits crop dray matter and grain yield potential .

The best genotypes under N-stress and non-stress conditions are presented in Table 4. When an advantage in both absolute yield under low- and high- N conditions was as an index of low-N stress tolerance, the parental populations Tuxpeno, DTP-1, Giza-2, DTP-2 and Tep-5, in descending order could be considered as the most tolerant populations and C-87, AED, BS-26 and BS-11 could be regarded as the most susceptible ones. Moreover, the F_1 crosses C-87 X Tuxpeno, Tep-5 X BS- 26, AED X BS-11, Giza-2 X Tep- 5 and Giza-2x BS-26 could be considered as the most low-N tolerant, while C-87 X DTP-2 , Tep-5 X Tuxpeno, DTP-2 X BS-11, DTP-2X Tuxpeno, and Giza-2 X AED could be regarded as the most susceptible population crosses. Results of Table (4) indicated that the low-N tolerance exhibited by different genotypes in terms of grain yield/plant and NUE was due to their low-N tolerance expressed by one or more yield components (Table 4) .

To describe the differences between low-N tolerant (T) and susceptible (S) genotypes, data for grain yield/plant, kernels/row, 100-kernel weight, rows/ear and NUE were averaged for the groups of genotypes (Table 5), one of them called low-N tolerant genotypes and the other group called low-N susceptible genotypes for parental populations and F_1 crosses.

Grain yield of the low-N tolerant (T) genotypes was greater than that of the susceptible (S) ones by 31.65 and 70.13 % for populations and F_1 crosses, respectively. Superiority of low-N tolerant over susceptible genotypes in grain yield/plant and NUE was due to the superiority in kernels/row (26.39 and 25.82 %), 100- kernel weight (13.38 and 35.67%) and rows/ear (7.75 and 15.24%) for parents and crosses, respectively. In general, the superiority of low-N tolerant over susceptible crosses was greater in F_1 than that observed in parental populations, which might be attributed to heterotic effects.

Heterobeltiosis

Mean squares due to the contrast of parents vs. crosses were significant or highly significant for grain yield, NUE, 100- kernel weight, kernels/row and rows/ear (Table 2), indicating the existence of significant heterosis for these traits. In general, average heterobeltiosis percentage under high-N (data not presented) were lower than that under low-N conditions.

Table 4. The best performing parental populations and F_1 crosses (in descending order) for grain yield/plant, kernels/row,100-kernel weight, rows/ ear and NUE, in 2003 season.

	Best Parents		Best F_1 Crosses	
Trait	High-N	Low-N	High-N	Low-N
Grain yield /plant (g)	Giza-2	Tuxpeno	C-87XTuxpeno	C-87XTuxpeno
	DTP-1	DTP-1	Tep-5XBS-26	Tep-5XBS-26
	Tuxpeno	Giza-2	Giza-2XBS-26	AEDXBS-11
	DTP-2	DTP-2	AEDXBS-11	Giza-2XTep-5
	Tep-5	Tep-5	Giza-2XTep-5	Giza-2XBS-26
Kernels/row	DTP-1	Tep-5	DTP-1XTep-5	Giza-2XDTP-1
	Tep-5	DTP-1	Giza-2XDTP-1	DTP-2XAED
	Giza-2	Giza-2	DTP-2XAED	AEDXBS-11
	C-87	C-87	AEDXBS-11	C-87XAED
	DTP-2	DTP-2	C-87XAED	C-87XDTP-1
100-kernel weight(g)	DTP-1	Tuxpeno	C-87XTuxpeno	C-87XTuxpeno
	Giza-2	DTP-1	Tep-5XBS-26	Tep-5XBS-26
	BS-11	Giza-2	Giza-2XBS-26	AEDXBS-11
	Tuxpeno	DTP-2	AEDXBS-11	Giza-2XBS-26
	DTP-2	Tep-5	Giza-2XBS-11	Giza-2XBS-11
Rows/ear	AED	AED	Tep-5XBS-11	Tep-5XBS-26
	DTP-1	C-87	Tep-5XBS-26	AEDXBS-26
	Tep-5	DTP-2	AEDXBS-26	BS-11XBS-26
	C-87	DTP-1	AEDXBS-11	Tep-5XBS-11
	DTP-2	Tep-5	BS-11XBS-26	DTP-2XTep-5
NUE(g/g)	Giza-2	Tuxpeno	C-87XTuxpeno	C-87XTuxpeno
	DTP-1	DTP-1	Tep-5XBS-26	Tep-5XBS-26
	Tuxpeno	Giza-2	Giza-2XBS-26	AEDXBS-11
	DTP-2	DTP-2	AEDXBS-11	Giza-2XTep-5
	Tep-5	Tep-5	Giza-2XTep-5	Giza-2XBS-26

Table 5: Mean performance of grain yield/plant, kernels/row, 100-kernel weight, rows/ear and NUE averaged over the 5 best and 5 poorest yielding parental populations and F_1 crosses in 2003 season.

	Parental Populations			F_1 Crosses		
Trait	T	S	%	T	S	%
Grain Yield/ plant (g)	121.25	92.10	31.65	151.84	89.25	70.13
Kernels/ row	28.35	22.43	26.39	31.63	25.14	25.82
100-Kernel wt.(g)	27.21	24.00	13.38	33.28	24.53	35.67
Rows/ear	13.49	12.52	7.75	14.97	12.99	15.24
NUE (g/g)	55.29	41.98	31.70	69.24	39.73	74.28

T = Tolerant, S = susceptible, % = Superiority.

Some population crosses showed significant or highly significant positive (desirable) heterobeltiosis estimates for grain yield, NUE and rows/ear (10 crosses), kernels/row (6 crosses) and 100-kernel weight (11 crosses)(Table 6). The 10 out of 36 population crosses showing significant positive heterobeltionsis for grain yield under low-N were Tep-5 x BS-26 (36.29%), AED X BS-11 (35.37%), AED X BS-26 (31.49%), C-87 X AED (27.90%), Giza-2 X Tep-5 (24.79%) , Giza-2 X BS-26 (24.03%), C-87 X Tep-

5 (21.57%), C-87 X BS-26 (19.05%), C-87 X Tuxpeno (16.82 %) and Giza-2 X DTP-1 (16.81 %). The positive heterobeltiosis estimates reached in some crosses to more than 30% for grain yield and NUE, namely, Tep-5 X B5-26, AED X BS-11 and AED X BS-26 under low–N conditions.

Table 6. Heterobeltiosis estimates (%) of F_1 population crosses under low-N conditions, in 2003 season.

Cross	Grain yield/plant	NUE	Rows/ear	Kernels/row	100-kernel wt.
Giza -2 X C-87	-3.88	-3.88	-4.48	-9.69	-3.46
Giza -2 X DTP-1	16.81*	16.79*	0.00	17.88*	21.71**
Giza -2 XDTP-2	-2.08	-1.91	-3.98	-12.84	-1.67
Giza -2 XTep-5	24.79**	24.78**	0.00	-10.59	24.36**
Giza -2 XAED	-13.55	-13.78	5.85*	-9.10	-24.63**
Giza -2 XTuxpeno	-3.44	-3.50	9.44**	7.72	20.26*
Giza- 2XBS-11	4.75	4.74	2.08	-7.00	17.56*
Giza- 2XBS-26	24.03**	24.03**	-4.11	-3.26	25.54**
C- 87 XDTP-1	12.45	12.43	0.00	3.11	21.00*
C-87XDTP-2	-31.40**	-31.41**	-4.97	-15.94	-8.26
C-87XTep-5	21.57**	21.58**	8.88**	-5.91	37.98**
C-87XAED	27.90**	27.91**	-6.77*	11.59	-20.25*
C-87XTuxpeno	16.82*	16.81**	4.92	-1.69	37.27**
C-87XBS-11	-7.91	-7.92	1.95	-8.21	3.11
C-87XBS-26	19.05*	19.03*	-1.01	-3.62	-5.24
DTP-1XDTP-2	-25.52**	-25.52**	-1.98	-5.65	-8.94
DTP-1XTep-5	2.35	2.34	0.98	2.34	8.85
DTP-1XAED	-16.08*	-16.08*	-1.92	-6.57	-24.52**
DTP-1XTuxpeno	-0.46	-0.42	3.96	0.12	24.78**
DTP-1XBS-11	5.19	4.69	5.44	-1.96	11.62
DTP-1XBS-26	-10.47	-10.90	-5.44	-12.57	-3.61
DTP-2XTep-5	-9.63	-9.63	10.86**	-13.94	-4.00
DTP-2XAED	-1.40	-1.39	-1.43	20.26**	-20.46*
DTP-2XTuxpeno	-38.38**	-38.38**	-1.01	1.63	-7.89
DTP-2XBS-11	-20.69**	-20.69**	-6.95	-5.08	-6.98
DTP-2XBS-26	8.76	8.76	-2.00	0.88	14.51
Tep-5XAED	-5.04	-5.03	9.74**	-11.37	-24.22**
Tep-5XTuxpeno	-38.10**	-38.10**	3.03	-3.01	-6.95
Tep-5XBS-11	-9.20	-9.20	10.61**	-14.83	-3.02
Tep-5XBS-26	36.29**	36.28**	18.69**	-4.35	4.67
AEDXTuxpeno	-8.38	-8.39	-8.72**	37.92**	25.33**
AEDXBS-11	35.37**	35.36**	0.02	34.89**	43.50**
AEDXBS-26	31.49**	31.46**	9.74**	12.00	-8.86
TuxpenoXBS-11	-4.68	-4.68	8.33**	13.27	-1.74
TuxpenoXBS-26	-31.58**	-31.58**	3.03	30.15**	-2.76
BS-11XBS-26	4.32	4.31	11.71**	21.77*	4.07
Average	0.28	0.25	2.07	1.34	4.41

* and ** indicate significant and highly significant at 0.05 and 0.01 levels of probability, respectively

In general, the population crosses of highest positive estimates of heterobeltiosis for grain yield and NUE (the best heterotic groups) in this study were those resulting from crossing parent populations of different origins, i.e. from crossing genetically diverse populations (see origin of populations in Table 1). This concslusion is in complete agreement with that reported by previous investigators. Falconer (1960) pointed out that if crossed populations do not differ in gene frequencies there will be no heterosis.

Moreover, Hallauer and Miranda (1988), stated that abundant heterosis manifested in a cross of two populations leads to conclusion that the parental varieties are more genetically diverse than the varieties manifest little or no heterosis. In the present study the population crosses showsing the highest heterobeltiosis under low-N could therefore be recommended for maize breeding programs aiming at developing single cross hybrids of high tolerance to low-N conditions.

When average heterobeltiosis for grain yield under low-N was calculated for each parent population across its hybrid combinations with other populations, maximum mean percentage of heterobeltionsis was shown by BS-26 (10.24%) followed by C-87 (6.82%), AED (6.29%), Giza-2 (5.93%) and Tep-5 (2.88%). The results suggest that these parent populations could be considered good sources of inbred lines that would show high heterobeltiosis (over dominance) in their F_1 single cross hybrid combinations under low-N conditions.

Significant positive heterobeltiosis shown by F_1 population crosses for grain yield and NUE under low-N could be attributed to significant positive heterobeltiosis for one or more components of grain yield (Table 6). Some investigators indicated that heterosis was more pronounced under low- than under high-N environments (Meseka *et al.*, 2006 in maize and Al-Naggar *et al.*, 2007 in grain sorghum).

Combining ability variances

Analysis of variance of general (GCA) and specific (SCA) combining abilities for studied traits, separately under high- and low-N conditions is presented in Table 7. Significant or highly significant mean squares due to GCA were observed for all studied traits under both high- and low-N conditions, with the exceptions of ears/plant and plant height under high- and low-N environments and kernels/ row under high-N. Highly significant mean squares due to SCA were also observed for all studied traits, except for ears/plant under low- and high-N and plant height, grain yield/plant and NUE under high-N conditions. This indicated the importance of both additive and non-additive types of genetic variances in the inheritance of most studied traits under both low- and high-N environments.

The magnitude of GCA variance was greater than that of SCA variance, as expressed by the GCA / SCA value of more than unity (Table 7) for 6 traits, namely 50% anthesis, 50% silking, ASI , 100- Kernel weight , grain yield / plant and NUE under both high- and low-N and for rows/ ear under low-N only , indicating that additive was more important than non-additive genetic variance in controlling the inheritance of these traits under both environments. On the other hand, for ears/plant , plant height and kernels/ row traits under both high- and low-N and rows/ear under high-N only , the GCA/ SCA value was less than unity, suggesting that non-additive was more important than additive genetic variance in controlling the inheritance of such traits (Table 7).A similar conclusion was reported by Rizzi. *et al.* (1993) for grain yield of maize under low- and high-N. Moreover, Chen *et al.* (2002) observed significant additive variance for maize grain yield under low-N.

Table 7. Mean squares due to general (GCA) and specific (SCA) combining ability for all studied traits of diallel population crosses of maize evaluated in 2003 season.

S.O.V	d.f	Mean squares									
		50% Anthesis	50% Silking	ASI	Ears /plant	Plant hieght	Rows /ear	Kernels /row	100-kernel weight	Grain yield /plant	NUE
		Low-N									
GCA	8	11.935**	8.723*	3.218**	0.0002	111.742	3.07**	16.28**	47.305**	1468.18**	305.25**
SCA	36	7.419**	7.332**	2.698**	0.0003	216.435**	1.73**	22.99**	39.377**	1329.82**	276.53**
Error	88	3.319	3.310	0.370	0.0003	77.850	0.24	3.87	6.550	105.86	21.96
GCA/SCA		1.610	1.190	1.190	0.6700	0.516	1.77	0.71	1.201	1.10	1.10
		High-N									
GCA	8	14.14**	12.04**	3.97**	0.009	168.77	0.59*	2.65	20.08**	283.46*	5.10*
SCA	36	6.03**	6.66**	1.44**	0.011	211.68	1.19**	8.36**	12.66**	157.59	2.82
Error	88	2.44	1.78	0.64	0.011	106.36	0.27	4.44	1.19	132.48	2.38
GCA/SCA		2.34	1.81	2.76	0.82	0.79	0.5	0.32	1.59	1.8	1.81

* and ** indicate significant and highly significant at 0.05 and 0.01 levels of probability, respectively.

General combining ability effects

Estimates of GCA effects of parental populations under high- and low-N environments are presented in Table 8. Significant positive GCA effects would be of interest for all studied traits, except for 50% anthesis, 50 % silking and ASI, where negative effects would be more agronmically useful. Significant positive (favourable) GCA effects for grain yield and NUE were shown by Tuxpeno and Giza-2 under low-N and C-87 under high-N. Giza-2 ranked the second with regard of GCA effects for grain yield and NUE under both high- and low-N conditions. Superiority of Tuxpeno, Giza-2 and C-87 in GCA effects for grain yield and NUE could be attributed to their superiority in GCA effects for 100-kernel weight (Table 8).

Table 8: General combining ability (GCA) effects of maize populations for all studied traits evaluated under two N levels.

population	50% Anthesis	50% Silking	ASI	Ears /plant	Plant hieght	Rows /ear	Kernels /row	100 Kernel weight	Grain yield /plant	NUE
Low-N										
Giza-2	-0.6*	-0.12	0.49**	-0.001	2.01	-0.55**	0.47	0.95*	6.55**	2.99**
C-87	-0.03	-0.12	-0.11	-0.001	-0.57	-0.08	-0.2	-0.59	-5.49**	-2.51**
DTP -1	0.64*	0.31	-0.33**	-0.005	0.57	0.05	1.35**	0.25	2.99	1.36
DTP -2	0.64*	0.22	-0.42**	-0.001	-1.54	-0.02	-0.67*	-2.18**	-12.22**	-5.57**
Tep -5	0.58*	0.49	-0.08	0.005	-1.89	0.56**	0.58	0.06	2.21	1.01
AED	-0.51	-0.42	0.09	-0.001	-2.57	0.22**	-0.17	-0.6	-4.33*	-1.98*
Tuxpeno	-0.33	0.06	0.4	-0.001	2.43	-0.13	-0.02	2.25**	10.05**	4.58**
BS- 11	0.49	0.64*	0.16	-0.001	-0.38	0.03	-0.94**	0.03	0.22	0.1
BS -26	-0.88**	-1.06**	-0.21*	-0.001	1.95	0.1	-0.4	-0.16	0.02	0.01
S.E.(g_i)	0.29	0.29	0.1	n.s	n.s	0.08	0.32	0.42	1.69	0.77
S.E.(g_i - g_j)	0.45	0.45	0.15	n.s	n.s	0.12	0.48	0.63	2.53	1.15
High-N										
Giza-2	-0.39	-0.6**	-0.22**	-0.004	2.07	-0.098	-0.333	0.89	3.31	0.45
C-87	0.79**	0.52*	-0.28**	-0.01	0.29	-0.044	-0.248	1.01**	4.02*	0.54*
DTP -1	-0.36	-0.36	-0.003	0.038	3.17	-0.059	0.328	0.21	1.24	0.17
DTP -2	0.28	0.19	-0.09*	0.014	0.29	-0.032	-0.224	-0.66**	-1.7	-0.23
Tep -5	0.61*	0.16	-0.46**	-0.004	0.1	0.123	-0.245	-1.32**	-4.16*	-0.56*
AED	-0.007	-0.09	-0.09*	-0.01	-3.29	0.062	-0.06	0.13	-2.36	-0.32
Tuxpeno	0.61*	0.85**	0.24**	-0.004	1.86	-0.059	0.086	0.34	1.25	0.17
BS -11	-0.29	0.43	0.72**	-0.01	-1.23	0.277**	0.343	0.19	1.59	0.21
BS -26	-1.27**	-1.09**	0.18**	-0.01	-3.26	-0.171	0.352	-0.8**	-3.19	-0.43
S.E.(g_i)	0.26	0.22	0.04	n.s	n.s	0.09	n.s	0.18	1.89	0.25
S.E.(g_i - g_j)	0.38	0.33	0.19	n.s	n.s	0.13	n.s	0.27	2.83	0.38

*** and ** indicate significant and highly significant at 0.05 and 0.01 levels of probability, respectively**

It is worthy to note that DTP-1 and Tep-5 populations showed relatively high positive GCA effects for grain yield and NUE under low-N, though these effects were not significant . Moreover, the *per se* performance for grain yield and NUE of these four populations (Tuxpeno, Giza-2, DTP-1 and Tep-5) under low-N was the best among all studied populations. These populations could therefore be considered as suitable source materials for practicing an efficient program of selection for improving traits related to low-N tolerance in maize, since they proved to be high *per se* yielders and high general combiners and consequently they are most likely to possess a large amount of additive genetic variance controlling such traits.

It is worthnoting that, the local population Giza-2 was superior over other parent populations for three criteria, i.e *per se* performance, GCA effects and average heterobeltiosis for grain yield and NUE. In this respect, Al-Naggar *et al.* (2008) were able to obtain a significant actual improvement for grain yield of 23.22 % under low-N *via* one cycle of S_1 recurrent selection practiced in this local cultivar (Giza-2).

Moreover, the superiority of DTP-1 in *per se* performance and GCA effects for grain yield and NUE in this study under low-N conditions is logic, since this population was already developed by CIMMYT for adaptation under drought stress conditions (a drought tolerant population). Several studies have reported good performance of maize genotypes selected for drought tolerance when they were grown under low-N conditions (Lafitte and Edmeades, 1995; Lafitte and Banziger, 1997; Banziger *et al.* 1999; Banziger *et al.*, 2002 and Shaboon, 2008).

Regarding flowering traits, BS-26 was the best general combiner for 50 % anthesis, 50% silking and ASI under low-N, since it showed the lowest negative and significant GCA effects for these traits. Moreover, under low-N, low and significant negative GCA effects (favourable) were shown by Giza-2 for 50 % anthesis and DTP- 1 and DTP-2 for ASI.

Under high-N conditions, BS-26 showed also the best GCA effects for 50% anthesis and 50% silking, followed by Giza-2 for 50% silking and ASI and C-87, DTP-2, Tep-5 and AED for ASI. The populations BS-26 , Giza-2, DTP-1 and DTP-2 which were good general combiners for shortening periods of 50% anthesis, 50 % silking and ASI in this experiment, could also be recommended for practicing selection to improve earliness and synchronization between anthesis and silking (ASI), which in turn could improve tolerance to low-N conditions.

Specific combining ability effects

Specific combining ability effects of the diallel F_1 population crosses under low-N conditions for some selected traits are presented in Table 9. Twelve out of 36 population crosses showed significant positive (favourable) SCA effects for grain yield and NUE traits under low-N . These crosses, in a descending order, were C-87 X Tuxpeno , AED X BS-11, Tep-5 X BS-26, C-87 X Tep-5 , DTP-2 X BS-26, C-87 X DTP-1, Giza-2 X BS-26, Giza-2 X Tep-5, Giza-2 X DTP-1, DTP-2 X AED, DTP-1 X Tuxpeno and AED X BS-26. These crosses exhibited also significant SCA effects in one or more of yield components and / or ASI (Table 9).

Summarizing the superiority of population crosses in their *per se* performance, heterosbeltiosis and SCA effects, it could be concluded that the crosses Tep-5 X BS-26, C- 87 X Tuxpeno and AED X BS-11 followed by the crosses Giza-2 X Tep-5, Giza-2 X BS-26, C-87 X Tep-5 and Giza-2 X DTP-1 were the best for the previous three criteria. Such population crosses could be recommended to the Egyptian maize breeding programs to isolate inbred lines and develop single cross hybrids of high tolerance to low-N stress conditions.

Table 9: Specific combining ability (SCA) effects of maize population crosses for some selected traits under low N .

crosses	ASI	Plant hieght	Rows /ear	Kernels /row	100 Kernel weight	Grain yield /plant	NUE
Giza -2 X C- 87	-0.10	7.87	-0.08	-1.92	-2.88*	-6.98	-3.19
Giza -2 X DTP-1	-1.22**	-2.59	0.53	4.83**	3.41*	13.34*	6.07*
Giza -2 XDTP-2	1.20**	-0.83	0.11	-2.35*	-0.77	1.81	0.90
Giza -2 XTep-5	0.87**	-5.47	-0.38	-1.73	3.77**	18.31**	8.34**
Giza -2 XAED	0.35	13.20**	1.29**	-1.78	-3.22*	-19.27**	-8.79**
Giza -2 XTuxpeno	0.38	1.87	0.98**	2.87**	0.51	5.01	2.28
Giza-2XBS-11	-1.38**	1.69	0.01	-0.41	2.03	-2.76	-1.27
Giza-2XBS-26	-0.68	5.69	-0.59*	0.12	4.41**	19.64**	8.95**
C- 87 XDTP-1	-0.62	15.32**	0.06	1.23	3.91**	20.17**	9.19**
C-87XDTP-2	0.47	-6.92	-0.49	-3.35**	-1.43	-20.08**	-9.17**
C-87XTep-5	-1.53**	12.44**	0.61*	0.34	5.14**	24.95**	11.38**
C-87XAED	1.29**	4.78	-0.92**	3.75**	-0.24	7.23	3.30
C-87XTuxpeno	0.99**	3.44	0.77**	-0.07	5.65**	46.05**	21.00**
C-87XBS-11	1.23**	0.26	0.21	-0.95	-2.67*	-8.92	-4.07
C-87XBS-26	-0.07	-12.07*	-0.26	-0.21	-2.09	0.54	0.25
DTP-1XDTP-2	1.02**	10.29*	-0.09	-0.83	-1.87	-18.43**	-8.41**
DTP-1XTep-5	0.35	-9.01	-0.45	1.25	0.43	0.40	0.18
DTP-1XAED	-1.50**	-6.68	-0.38	-1.61	-2.49	-15.05**	-6.86**
DTP-1XTuxpeno	0.20	-1.68	0.64*	0.18	2.51	12.84*	5.88*
DTP-1XBS-11	-0.56	3.14	0.68**	0.50	1.29	5.80	2.64
DTP-1XBS-26	-0.19	-6.53	-0.86**	-3.10**	-2.86*	-12.71*	-5.79*
DTP-2XTep-5	-1.22**	-2.91	1.00**	-1.59	-0.75	-2.78	-1.28
DTP-2XAED	-0.74*	3.41	-0.06	5.68**	1.27	13.23*	6.03*
DTP-2XTuxpeno	-0.38	6.08	0.09	0.54	-3.94**	-26.22**	-11.96**
DTP-2XBS-11	0.53	-13.10**	-0.87**	-0.34	-1.45	-13.49*	-6.16*
DTP-2XBS-26	0.23	-0.10	-0.28	0.72	3.93**	20.54**	9.36**
Tep-5XAED	-0.07	5.44	0.71**	-1.33	-2.91*	-6.47	-2.95
Tep-5XTuxpeno	-1.38**	-13.56**	-0.40	1.02	-6.17**	-40.25**	-18.35**
Tep-5XBS11	1.20**	16.59**	0.44	-1.59	-2.95*	-15.76**	-7.18**
Tep-5XBS-26	-1.10**	6.26	1.43**	1.01	6.83**	36.17**	16.49**
AEDXTuxpeno	-0.22	-4.22	-1.13**	2.83**	2.62	8.83	4.02
AEDXBS-11	0.68*	5.93	-0.09	4.88**	6.87**	38.05**	17.36**
AEDXBS-26	-0.62	2.59	1.17**	-0.12	3.05*	11.05*	5.04*
TuxpenoXBS-11	-0.28	-3.41	0.40	-0.26	2.36	9.58	4.37
TuxpenoXBS-26	1.08**	-1.41	-0.08	4.07**	-4.96**	-28.73**	-13.10**
BS-11XBS-26	-0.01	2.75	0.89**	2.99**	-1.01	-0.83	-0.38
S.E(S_{ij})	0.32	4.66	0.26	1.04	1.35	5.43	2.47
S.E (S_{ij} - S_{ik})	0.47	6.87	0.38	1.53	1.99	8.01	3.65
S.E(S_{ij} - S_{kl})	0.45	6.52	0.36	1.45	1.89	7.59	3.46

* and ** indicate significant and highly significant at 0.05 and 0.01 levels of probability, respectively

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قوة الهجين والقدرة الائتلافية في الهجن الدائرية بين بعض عشائر الذرة الشامية تحت ظروف نيتروجين التربة المنخفض

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أجريت هذه الدراسة بهدف تحديد أفضل العشائر تحت الدراسة والهجن الناتجة منها للتحمل العالي لنقص نيتروجين التربة وكذلك دراسة قوة الهجين والقدرة علي الائتلاف تحت ظروف نيتروجين التربة المنخفض والعالي . في موسم 2002 تم التهجين بين 9 عشائر مفتوحة التلقيح في نظام الهجن الدائرية (ماعدا الهجن العكسية) . وفي موسم 2003 تم تقييم التسعة عشائر الأبوية مع الهجن الناتجة منها (36 هجين) تحت ظروف النيتروجين العالي والمنخفض . كان متوسط المربعات الراجع للتراكيب الوراثية وكذلك لمستويات النيتروجين معنويا أو عالي المعنوية لكل الصفات المدروسة ، ما عدا عدد الكيزان للنبات . كانت تقديرات قوة الهجين للأب الأفضل ، أعلي تحت ظروف النيتروجين المنخفض عنها تحت ظروف النيتروجين العالي . وقد أظهرت عشرة هجن (من مجموع 36 هجين) ، قيم موجبة معنوية لتقديرات قوة الهجين لصفة المحصول تحت ظروف النيتروجين المنخفض . وكانت أعلي قيم لقوة الهجين لصفتي المحصول وكفاءة استخدام النيتروجين ، هي الناتجة من تهجين عشائر أبوية من مصادر مختلفة . كان التباين الراجع للقدرة العامة أكبر من التباين الراجع للقدرة الخاصة علي الائتلاف في 6 صفات متضمنة المحصول وكفاءة استخدام النيتروجين تحت ظروف النيتروجين العالي والمنخفض وهذا يدل علي أن التباين الراجع الي الفعل المضيف للجينات كان أكثر أهمية من التباين الراجع إلي الفعل غير المضيف . كانت العشائر Tuxpeno ، Giza-2 ، DTP-1 و Tep-5 هي أفضل العشائر من حيث الأداء وتأثيرات القدرة العامة علي الائتلاف لصفتي المحصول وكفاءة استخدام النيتروجين ويمكن إعتبارهم أفضل المواد الوراثية تحت الدراسة لتحسين الصفات التي لها علاقة بتحمل النيتروجين المنخفض في برامج تحسين عشائر الذرة الشامية بالانتخاب . تفوقت بعض الهجن بين العشائر الأبوية في الاداء في حد ذاته وفي قوة الهجين وتأثيرات القدرة الخاصة علي الإئتلاف وهذه الهجن مرتبة تنازليا هي Tep-5 XBS-26 ، C-87X Tuxpeno ، AEDX BS-11 ، Giza-2 X Tep-5 ، Giza-2 X BS-26 ، C-87 X Tep-5 و Giza-2 XDTP-1 . هذه الهجن يمكن التوصية باستخدامها في البرنامج القومي لتربية الذرة الهجين وذلك بعزل سلالات مرباة داخليا لإنتاج هجن فردية عالية التحمل لظروف الإجهاد الناتج عن نقص نيتروجين التربة .