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Selection of maize (*Zea mays*) hybrids for plant density tolerance

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ABSTRACT

Plant density tolerance (PDT) is one of the most important trait for breeders. The study was carried out at Sakha Research Station, Egypt in 2016. Half diallel crosses among 10 yellow maize (*Zea mays* L.) inbred lines were made. The resulting 45 hybrids and commercial check SC162 were evaluated under 2 nitrogen fertilizer levels (N_1= 286 and N_2=357 kg N/ha) and 3 plant densities (D_1=59351 plant/ha, D_2=71846 plants/ha and D_3=84341 plant/ha) in 2017 to identify the superior hybrids at high plant densities and estimate combining ability variance and effects at various plant densities for grain yield. The mean squares due to nitrogen fertilizer (N) was not significant, while the mean squares due to plant density (D), N×D interaction, hybrids (H), H × N, H × D and H × N × D were highly significant. Also the mean squares due to general combining ability (GCA) and specific combining ability (SCA) and their interactions with N, D, and N×D were highly significant. SCA or non-additive gene action was the main influence in the inheritance and was more affected by N, D and N×D interaction for grain yield. The best inbred lines for GCA effects, viz. P3, P8 and P10 can be used in maize breeding program to give high yield in various environmental conditions especially for plant density tolerance. The best hybrids for SCA effect under most environments especially high plant densities were P1 × P3, P1 × P8, P2 × P6, P4 × P5, P4 × P8, P5 × P7 and P8 × P10. The hybrid P8 × P10 had high significant positive superiority. These hybrids can be upgraded to other stages of evaluation in the maize breeding program, especially for plant density tolerance.

Key words: Maize, New hybrids, Plant density, Selection, Tolerance

Maize (*Zea mays* L.) is one of the top three most important cereal crops in the world (Russell 1991). It is grown on more than 100 million ha worldwide (FAO. Agric. 2015). To meet present and future needs, productivity per unit area must be increased through plant breeding and improved cultural practices (Duvick 2005, Lee and Tollenaar 2007). The breeders work to develop new hybrids having high yield potential under stress of free growing conditions.

Also many studies have suggested that breeders have not significantly changed yield potential, but they have increased stress tolerance for obtain high yield potential under a wider range of environmental conditions (Tokatlidis and Koutroubas 2004). Breeding to plant density tolerance is one of the most important objectives of breeders. Meanwhile, concerning cultural practices like, fertilization, plant density, irrigation, planting dates and weed control are the most important factors affecting grain yield. Optimum conditions must be selected of these factors to give the highest grain yield for each hybrid. Sangoi (2000) found that increased plant density is an important factor impacting grain yield on corn-belt. Several maize studies have evaluated hybrids at different plant densities ranging from 30000 plants/ha to 100000 plants/ha. The results from those studies exhibited that plant density and grain yield per unit area trend together in an increasing fashion over time since 1930 in the USA (USDA-NASS 2012). Based on these results, the important way to increase grain yield per unit area is to increase the plant density (Brekke *et al.* 2011). Some hybrids yield more as plant density is increased while others exhibit no increase or even yield loss (Duvick and Cassman 1999, Grassini *et al.* 2011).

Several studies have shown the effect of some traits on plants, ability to density tolerance. Lambert and Johnson (1978) stated that upright leaf angle and tassels with fewer branches have been linked to increased grain yield under high plant density. Duvick and Cassman (1999) found that tassel size decreased due to increased grain yield. Carcova and Otegui (2001) reported that under high plant density improved kernel set led to improved grain yield and was associated with a shorter anthesis-silking interval (ASI). Brian and Mumm (2013) found that leaf angle and upper stem diameter were the two traits highly correlated with grain yield, suggesting key influence in PDT. Borras *et al.* (2003) found that poor stay green (higher rate of leaf senescence) under high plant density is associated with poor

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assimilate supply. Increased lodging and increased plant and ear height have also been associated with less tolerance to plant density stress (Edmeades and Lafite 1993). Choosing the right plant density in the selection environment has been proposed as a successful way to improve stress tolerance (Zavala-Garcia *et al.* 1992). The association between inbred lines and their hybrid progenies were increased when genetic materials were developed at higher plant densities (Carena *et al.* 2003). The objectives of this research were to identify the superior hybrids for grain yield at high plant densities and to estimate combining ability and type of gene action under nitrogen levels and plant density.

MATERIALS AND METHODS

This investigation was carried out at Sakha Agricultural Research Station, Egypt. Ten yellow maize inbred lines, P1(Sk 2), P2 (Sk 10), P3 (Sk 11), P4 (GZ 658),P5 (GZ 666), P6 (Sk 8008), P7 (GM 1004), P8 (Sk 5006), P9 (Sk 5014/3) and P10 (Sd 3120) were used in this study. These inbred lines have high general combining ability and some traits that have a relation to the plant density tolerance. In 2016 growing season inbred lines were crossed in half diallel cross. The resulting 45 hybrids and one commercial hybrid SC 162 were evaluated under three plant densities, D_1= 59351 plants/ha (optimum plant density in Egypt), D_2= 71846 plants/ha and D3= 84341 plants/ha, and two nitrogen fertilizer levels, N_1=286 kg N/ha (optimum fertilization in Egypt) and N_2= 357 kg N/ha in one trial in 2017 growing season. split-split plot design with three replications was used; the two nitrogen levels were located at the main plots, the three plant densities were placed in the sub-plots and 46 hybrids were located at the sub-sub plots. Plot size consisted of, 4 m row 0.8 m apart and the hills were spaced 21 cm at D1, 17. 5 cm at D2 and 15 cm apart at D3. All agronomic field operations were practiced with ordinary field maize cultivation except nitrogen fertilization; the quantity 286 and 357 kg N/ha was divided into equal doses; the first dose was added with the first irrigation and the second dose was added with the second irrigation. Statistical analysis of variance for grain yield was recorded according to Snedecor and Cochran (1967). The variations among hybrids were further partitioned into the general and specific combining ability components, also general and specific combining ability effects for ten inbred lines were computed according to Griffing (1956) method-4 model-1.

RESULTS AND DISCUSSION

Analysis of variance for 46 hybrids under two nitrogen levels and three plant densities and their interactions for grain yield are presented in Table 1. The results exhibited that the mean squares due to nitrogen levels (N) was not significant. While the mean squares due to plant density (D) and D × N interaction was highly significant, meaning that grain yield was affected by D and N × D interaction. Also the mean squares due to hybrids H and their interactions, H × N, H × D and H × N × D were highly significant. This means that there were differences among hybrids and these differences were affected by D and interaction between D × N. Abd El-Aty (1987) reported that the differences between genotypes and their interactions with N, D and N × D were significant for grain yield. Mosa (2001) found that grain yield was affected by D, N and not affected by N × D interaction. Shrestha *et al.* (2018) found that nitrogen levels and interaction between N × D were not significant for grain yield.

Table 1 Analysis of variance for 46 hybrids under two nitrogen levels, three plant densities and their interactions for grain yield (kg/plot)

SOV	df	SS	MS
Rep	2	3.462	1.731
Nitrogen levels (N)	1	3.930	3.930
Error (a)	2	0.898	0.449
Plant density (D)	2	6.148	3.074**
D × N	2	3.458	1.729**
Error (b)	8	1.502	0.187
Hybrids (H)	45	77.005	1.711**
H × N	45	17.070	0.379**
H × D	90	17.114	0.190**
H × D × N	90	24.340	0.270**
Error (c)	540	51.550	0.095

** Significant at 0.01 level of probability.

Means of two nitrogen levels, three plant densities and their interaction for grain yield (Table 2) showed that as an average over two nitrogen levels the high plant density D_3 produced the highest grain yield followed by D2 and the lowest value was recorded for D1. Meanwhile the highest grain yield was obtained from N2D3, while the lowest value was obtained from N1D1. (Hunter *et al.* 1970), (Katta *et al.* 1975), Mosa (2001) and Brian and Mumm (2013) reported that increasing plant density led to increase in grain yield. (Nawar *et al.* 1992), Mohamed (1999), Abdel-Aty (2007) and (Shrestha *et al.* 2018) found that with increased nitrogen fertilizer up to 286 kgN/ha the grain yield increased.

Means of hybrids under N1 across three plant densities for grain yield ranged from 2.48 kg/plot for P5 × P8 to 4.12 kg/plot for P4 × P8, the highest hybrids were P4 × P8, P1 × P8, P3 × P4 and P8 × P10, respectively (Table 3). Means of hybrids under N2 across three plant densities ranged from 2.95 kg/plot for P5 × P8 to 4. 58 kg/plot for P1 × P3, the best hybrids were P1 × P3, P8 × P10, P3 ×P8,

Table 2. Means of two nitrogen levels, three plant densities and their interaction for grain yield

Nitrogen Level	Plant density			Mean
	D1	D2	D3	
N1	3.28	3.55	3.61	3.48
N2	3.60	3.58	3.70	3.62
Mean	3.44	3.56	3.65	-

P1 × P8 and P3 × P5, respectively. In general, the hybrids P1 × P8 and P8 × P10 give high grain yield under both N1 and N2 across three plant densities. Meanwhile means hybrids under D1 across two nitrogen levels ranged from 2. 65 kg/plot for P5 × P6 to 4. 29 kg/plot for P8 × P10 the best hybrids were P8 × P10, P4 × P8, P3 × P5, P1 × P5 and P1 × P3, respectively. Also, under D2 the means hybrids ranged from 2.57 kg/plot for P5 × P8 to 4. 14 kg/plot for P1 × P3, the better hybrids were P1 × P3, P1 × P8, P8 × P10, P3 × P8, respectively. The hybrids under D3 ranged from 2.72 kg/plot for P5 × P8 to 4.25 kg/plot for P1 × P8, the highest hybrids were P1 × P8, P3 × P8, P1 × P3, P4 × P8, P8 × P10, P2 × P10 and P3 × P4, respectively. From above results, the hybrids P1 × P3, P1 × P8, P3 × P8 and P8 × P10 gave high grain yield under both high densities D2 and D3.

Mean grain yield of hybrids under N1D1 were ranged from 2. 26 kg/plot for P5 × P6 to 4. 11 kg/plot for P4 × P8, the better hybrids for grain yield were P4 × P8, P8 × P10 and P1 × P4, respectively, under N1D2 ranged from 2. 51 kg/plot for P5 × P8 to 4. 28 kg/plot for P1 × P8, the highest hybrids for grain yield were P1 × P8 , SC 162, P1 × P9 , P3 × P4 , P4 × P8 , P8 × P10 and P4 × P5, respectively, under N1D3 ranged from 2.57 kg/plot for P5 × P8 to 4. 25 kg plot for P7 × P10, the highest hybrid for grain yield were P7 × P10, P4 × P8, P1 × P8 , P3 × P4 , P7 × P8 , P5 × P9 , P5 × P10 and P5 × P7, respectively, under N2D1 ranged from 2.68 kg/plot for P1 × P6 to 4.68 kg/plot for P8 × P10, the best hybrids were P8 × P10, P3 × P5, P1 × P3, SC 162, P1 × P5, P3 × P9, P5 × P9, P2 × P7, P3 × P7 and P4 × P8, respectively under N2D2 ranged from 2. 64 kg/plot for P5 × P8 to 4. 58 kg/plot for P1 × P3, the superiority hybrids

Table 3. Means performance of the best hybrids under two nitrogen levels and three plant densities for grain yield (kg/plot)

N1		N2		D1		D2		D3	
Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean
P4 x P8	4.129	P1 x P3	4.582	P8 x P10	4.292	P1 x P3	4.145	P1 x P8	4.258
P1 x P8	3.998	P8 x P10	4.478	P4 x P8	4.120	P1 x P8	4.118	P3 x P8	4.195
P3 x P4	3.912	P3 x P8	4.126	P3 x P5	3.988	P8 x P10	4.087	P1 x P3	4.193
P8 x P10	3.879	P1 x P8	4.091	P1 x P5	3.945	P4 x P8	3.985	P4 x P8	4.160
P5 x P7	3.846	P3 x P5	4.047	P1 x P3	3.907	P3 x P8	3.907	P8 x P10	4.157
P7 x P10	3.843	P1 x P5	3.936	P3 x P 9	3.785	P2 x P10	3.880	P2 x P10	4.150
P1 x P4	3.837	P2 x P10	3.922	P1 x P9	3.752	P1 x P4	3.850	P3 x P4	4.002
P2 x P10	3.741	P4 x P8	3.914	P7 x P10	3.748	P4 x 10	3.813	P2 x P8	3.993
P7 x P8	3.729	P3 x P9	3.913	P1 x P4	3.747	P4 x P5	3.807	P5 x P7	3.945
P3 x P8	3.693	P2 x P8	3.896	P5 x P7	3.692	P3 x P10	3.802	P3 x P9	3.932
Check SC 162	3.982	SC 162	4.090	SC 162	4.103	SC 162	3.873	SC 162	4.131
	LSD 0.05 (0.28)					LSD 0.05 (0.34)			
	LSD 0.01 (0.37)					LSD 0.01 (0.45)			

Table 4. Means performance of the best hybrids under the combination between two nitrogen levels and three plant densities and their means across all environments for grain yield (kg/plot)

N1D1		N1D2		N1D3		N2D1		N2D2		N2D3		Mean	
Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean	Hybrid	Mean
P4 × P8	4.117	P1 × P8	4.280	P7 × P10	4.257	P8 × P10	4.683	P1 × P3	4.583	P1 × P3	4.817	P8 × P10	4.178
P8 × P10	3.900	P1 × P9	4.210	P4 × P8	4.200	P3 × P5	4.437	P8 × P10	4.200	P8 × P10	4.550	P1 × P3	4.082
P1 × P4	3.863	P3 × P4	4.140	P1 × P8	4.187	P1 × P3	4.391	P2 × P4	4.133	P3 × P8	4.527	P4 × P8	4.022
P2 × P9	3.773	P4 × P8	4.070	P3 × P4	4.130	P1 × P5	4.177	P1 × P8	4.110	P8 × P9	3.460	P1 × P8	4.023
P5 × P10	3.773	P4 × P10	3.983	P7 × P8	4.120	P3 × P9	4.170	P3 × P8	4.080	P7 × P9	4.460	P3 × P8	3.909
P1 × P5	3.713	P8 × P10	3.973	P5 × P9	4.063	P5 × P9	4.050	P8 × P9	3.983	P2 × P10	4.447	P2 × P10	3.832
P7 × P8	3.713	P4 × P5	3.973	P5 × P10	4.050	P2 × P7	4.027	P7 × P8	3.973	P1 × P8	4.350	P3 × P9	3.826
P7 × P10	3.710	P1 × P4	3.950	P5 × P7	4.010	P3 × P7	4.010	P4 × P8	3.900	P2 × P8	4.233	P3 × P5	3.791
P1 × P9	3.657	P2 × P10	3.903	P4 × P5	3.953	P4 × P8	3.943	P4 × P9	3.877	P4 × P10	4.210	P3 × P4	3.785
P2 × P10	3.610	P3 × P9	3.890	P3 × P9	3.927	P2 × P8	3.817	P1 × P5	3.817	P3 × P10	4.130	P3 × P10	3.684
Check SC 162	3.523	SC 162	4.216	SC 162	3.906	SC 162	4.383	SC 162	3.530	SC 162	4.036	SC 162	3.932
		LSD 0.05 (0.49)								LSD 0.05 (0.21)			
		LSD 0.01 (0.64)								LSD 0.01 (0.26)			

were P1 × P3 , P8 × P10, P2 × P4 , P1 × P8 , P3 × P8 , P8 × P9 and P4 × P8, respectively and under N2D3 ranged from 2. 87 kg/plot for P5 × P8 to 4.81 kg/plot for P1 × P3 , the favorable hybrids for grain yield were P1 × P3, P8 × P10 , P3 × P8 , P7 × P9 , P2 × P10, P1 × P8 , P2 × P8 , P3 × P10 and SC 162 (Table 4). From above results, the hybrid P8 × P10 had high grain yield under N2D1, N2D2 and N2D3 followed by P4×P8 under N1D1, N1D2, N1D3, N2D1 and N2D2, P1 × P8 under N1D2, N1D3, N2D2, and N2D3, and P1×P3 under N2D1, N2D2 and N2D3. Mean hybrids across two nitrogen levels and three plant density (Table 4) exhibited that the best hybrids for grain yield were P8×P10 4. 17 kg/plot, followed by P1 × P3 4. 08 kg/plot, P1 × P8 4. 02 kg/plot and P4 × P8 4. 02 kg/plot. These hybrids can be used as high yielding hybrids especially under high density.

Table 5 Analysis of variance for general and specific combining ability and their interaction with nitrogen levels and plant density for grain yield (kg/plot)

SOV	df	SS	MS
Hybrids (H)	44	72.80	1.65**
GCA	9	33.94	3.88**
SCA	35	38.86	1.11**
H×N	44	17.06	0.38**
GCA ×N	9	4.45	0.44**
SCA ×N	35	12.6	0.36**
H× D	88	16.73	0.19**
GCA×D	18	3.12	0.17**
SCA×D	70	13.6	0.19**
H×N×D	88	23.31	0.26**
GCA×N×D	18	4.3	0.23**
SCA×N×D	70	19.04	0.27**
Error	528	49.60	0.093
K^2 GCA / K^2SCA		0.46	
K^2GCA×N /K^2SCA × N		0.15	
K^2 GCA × D / K^2SCA× D		0.09	
K^2 GCA × N × D / K^2SCA × N×D		0.052	

** Significant at 0.01 level of probability.

Analysis of variance for general and specific combining ability and their interactions with nitrogen levels and plant density for grain yield showed that both mean squares of GCA and SCA were highly significant (Table 5). These indicate that additive and non-additive gene actions were important in the inheritance of grain yield. These results are agreement with Mosa (2010), Arafa (2012) and Abu-Shosha (2017). Also, mean squares due to the interactions between GCA × N, GCA × D, GCA × N × D, SCA × N, SCA × D and SCA × N × D were highly significant, meaning that both additive and non-additive gene action were affected by environment. The same results were obtained by Abd El-Aty (1987), Mosa (2001) and Abd El-Aty and Darwish (2006). Estimates of K^2 GCA and K^2 SCA and their interactions with N, D and N × D for grain yield showed that K^2SCA was higher than K^2 GCA. These indicate that the non-additive gene action was main influence in the inheritance of grain yield. Also the K^2 SCA was higher than K^2GCA when interacted with N, D and N × D, meaning that non-additive gene action was more affected by N, D and N × D than additive gene action for grain yield. (Mosa *et al.* 2016) found that SCA was more important than GCA in the inheritance of grain yield. EL-Shamarka *et al.* (1994) and Mosa (1996) found that the ratios of GCA × N / SCA × N, GCA × D / SCA × D and GCA × N × D /SCA × N × D were less than unity. On the other hand, Abd El-Aty and Darwish (2006) found that GCA was more important than SCA in the inheritance of grain yield.

Data over density levels showed that the best inbred

Table 6. Estimate of general combining ability under two nitrogen levels and three plant densities for grain yield (kg/plot)

Inbred line		GCA effect				
		N1	N2	D1	D2	D3
P1		0.1183**	0.0893**	0.1393**	0.1614**	0.0107
P2		-0.1179**	0.0446	-0.0955*	0.0095	-0.0239
P3		0.1341**	0.2804**	0.2361**	0.2085**	0.1771**
P4		0.0895**	-0.0670*	-0.0812	0.0739	0.0411
P5		-0.1998**	-0.1048**	-0.1005*	-0.2120**	-0.1443**
P6		-0.2538**	-0.3777**	-0.3922**	-0.2832**	-0.2718**
P7		-0.0448	-0.1542**	-0.0249	-0.1659**	-0.1077*
P8		0.0808	0.1830**	0.1428**	0.0989*	0.1540**
P9		-0.003	-0.0425	-0.0383	-0.0390	0.0090
P10		0.1967**	0.1489**	0.2145**	0.1480**	0.1559**
LSD gi	0.05	0.067			0.082	
	0.01	0.087			0.108	
LSD(gi–gj)	0.05	0.100			0.122	
	0.01	0.131			0.161	

Table 7 Estimate of general combining ability effect for 10 inbred lines under the combination between two nitrogen levels and three plant densities

Inbrd line		GCA effect						Mean
		N1D1	N1D2	N1D3	N2D1	N2D2	N2D3	
P1		0.2193 **	0.1932**	-0.0577	0.0593	0.1296*	0.0790	0.1038**
P2		-0.1445*	-0.0414	-0.167**	-0.0466	0.0604	0.1198*	-0.0367
P3		0.1293*	0.2019**	0.0711	0.3430**	0.2150**	0.283**	0.2072**
P4		0.0138	0.1069	0.1478*	-0.1762**	0.0408	-0.065	0.0113*
P5		-0.2566**	-0.198**	-0.1443*	0.0555	-0.2254**	-0.144*	-0.1523*
P6		-0.3795**	-0.188**	-0.193**	-0.4049**	-0.3779**	-0.350**	-0.3158*
P7		-0.0495	-0.1489*	0.0640	-0.0003	-0.1829**	-0.279**	-0.0995*
P8		0.1238*	-0.0048	0.1232*	0.1618**	0.2025**	0.1848**	0.1319*
P9		0.0297	-0.0752	0.0365	-0.1062	-0.0029	-0.018	-0.0228
P10		0.3143**	0.1553**	0.1207*	0.1147*	0.1408*	0.191**	0.1728*
LSD gi	0.05			0.116				0.047
	0.01			0.153				0.625
LSD(gi –gj)	0.05			0.173				0.070
	0.01			0.228				0.093

lines for GCA effects (positive and significant) were P1, P3, P4, P8 and P10 under (N1), P1, P3, P8 and P10 at (N_2) (Table 6). By the same way the best inbred lines for GCA effects over nitrogen levels were; P1, P3, P8 and P10 under D1 and D2 P1, P3, P8 and P10 under D3. From the above results the inbred lines P1, P3, P8 and P10 had the best GCA effects under two nitrogen levels and three plant densities except of the P1 under D3.

Estimates of general combining ability effects under the combination between two nitrogen levels and three plant densities and their mean for grain yield showed that better inbred lines for GCA effects were P1, P3, P8 and P10 under N1D1, P1, P3 and P10 under N1D2, P4, P8 and P10 under N1D3, P3,P8 and P10 under N2D1, P1,P3,P8 and P10 under N2D2 and P2,P3,P8 and P10 under N2D3. In general, the best inbred line for GCA effects for grain yield across all environments were P1, P3, P4, P8 and P10 (Table 7). These inbred lines can be used in maize breeding program to produce high yielding hybrids that bear various environmental conditions especially for plant density tolerance.

Estimates of specific combining ability effects of the best F1 hybrids for grain yield at nitrogen levels across plant densities showed that the best hybrids for SCA effects (positive and significant) were P1 × P8, P2 × P3, P2 × P6, P2 × P10, P3 × P4, P4 × P5, P4 × P8, P5 × P, P5 × P10, P7

Table 8. Estimate of specific combining ability effect of best hybrid under two nitrogen levels and three plant densities for grain yield

N1		N2		D1		D2		D3	
Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA
P5 × P7	0.6116**	P1 × P3	0.5955**	P4 × P8	0.5355**	P5 × P7	0.5576**	P5 × P7	0.5500**
P2 × P6	0.4242**	P8 × P10	0.5288**	P2 × P6	0.5115**	P4 × P5	0.3912**	P1 × P8	0.4467**
P4 × P8	0.4800**	P5 × P7	0.3830**	P8 × P10	0.5015**	P1 × P8	0.2945**	P1 × P3	0.3585**
P4 × P5	0.3139**	P1 × P5	0.334**	P3 × P5	0.4199**	P8 × P10	0.2762**	P7 × P9	0.3350**
P1 × P8	0.2802**	P7 × P9	0.2985**	P1 × P.5	0.4734**	P2 × P6	0.2684*	P4 × P5	0.3079**
P5 × P10	0.2567**	P3 × P5	0.2540**	P5 × P7	0.3842**	P4 × P8	0.2487*	P6 × P10	0.2740*
P7 × P8	0.2144**	P2 × P7	0.2437**	P1 × P4	0.2557**	P1 × P3	0.2116*	P5 × P9	0.2717*
P7 × P10	0.2128**	P2 × P6	0.1994**	P2 × P9	0.2059*	P3 × P5	0.1866	P3 × P8	0.2169*
P3 × P4	0.2100**	P4 × P8	0.1813**	P1 × P9	0.2178*	P6 × P7	0.1689	P6 × P9	0.2158*
P2 × P10	0.1837**	P1 × P8	0.1784*	P2 × P7	0.1192	P1 × P4	0.0512	P2 × P10	0.2994**
	LSD Sij 0.05 (0.176)						LSD Sij 0.05 (0.216)		
	0.01 (0.232)						0.01 (0.284)		
	LSD Sij-Skl 0.05 (0.245)						LSD Sij-Skl 0.05 (0.300)		
	0.01 (0.322)						0.01 (0.395)		

Table 9. Estimate of specific combining ability effect of the best hybrid under the combination among two nitrogen level, three plant densities and their mean for grain yield

N1D1		N1D2		N1D3		N2D1		N2D2		N2D3		Mean	
Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA	Hybrid	SCA
P4 × P8	0.7006**	P5 × P7	0.6758**	P5 × P9	0.565**	P8 × P10	0.8196**	P1 × P3	0.6632**	P7 × P9	1.0695**	P5 × P7	0.4973**
P5 × P7	0.6743**	P4 × P5	0.5133**	P1 × P8	0.515**	P2 × P6	0.5675**	P2 × P4	0.4565**	P1 × P3	0.7662**	P4 × P8	0.3307**
P2 × P9	0.6097**	P2 × P6	0.515**	P5 × P7	0.485**	P5 × P9	0.5133**	P5 × P7	0.4394**	P5 × P7	0.6154**	P8 × P10	0.3258**
P1 × P5	0.4722**	P4 × P8	0.4162**	P7 × P10	0.466**	P2 × P7	0.4863**	P7 × P8	0.3782*	P8 × P10	0.4858**	P2 × P6	0.3118**
P2 × P6	0.4556**	P1 × P8	0.3866*	P5 × P10	0.468**	P1 × P5	0.4746**	P1 × P5	0.3369*	P2 × P10	0.4475**	P1 × P8	0.2293**
P5 × P10	0.4372**	P1 × p9	0.367*	P7 × P8	0.327*	P3 × P5	0.4508**	P3 × P5	0.3315	P4 × P10	0.3962*	P4 × P5	0.2287**
P3 × P5	0.3889*	P2 × P8	0.3012*	P4 × P8	0.323*	P6 × p8	0.3658*	P2 × P7	0.2269	P1 × P8	0.3779*	P1 × P3	0.2228**
P7 × P8	0.3639*	P8 × P10	0.2712	P6 × P9	0.321*	P4 × P8	0.3704*	P8 × P10	0.2811	P3 × P8	0.3704*	P3 × P5	0.1883**
P1 × P4	0.3518*	P3 × P4	0.2795	P4 × P5	0.344*	P1 × P3	0.3571*	P6 × P7	0.2753	P6 × P10	0.2775	P1 × P5	0.169**
P3 × P6	0.1818	P2 × P10	0.2379	P3 × P4	0.305*	P3 × P9	0.3458*	P4 × P5	0.2690	P4 × P5	0.2716	P2 × P10	0.1477*
	LSD Sij		0.05	0.305								LSD S_{ij} 0.05	0.124
			0.01	0.402								0.01	0.164
	LSD Sij-Skl		0.05	0.424								LSD $S_{ij} - S_{kl}$ 0.05	0.173
			0.01	0.559								0.01	0.288

× P8 and P7 × P10 under N1, P1 × P3, P1 × P5, P1 × P8, P2 × P6, P2 × P, P3 × P, P4 × P8, P5 × P, P6 × P10, P7 × P9 and P8 × P10 under N2 (Table 8). The best hybrids for SCA effects under plant densities across nitrogen levels were P1 × P4, P1 × P5, P1 × P9, P2 × P6, P2 × P9, P3 × P, P4 × P8, P5 × P7 and P8 × P10 under D_1, P1 × P,P1 × P8,P2 × P6,P4 × P5,P4 × P8,P5 × P7 and P8× P10 under D_2,P1 × P3,P1 × P8,P2 × P6,P3 × P8,P4 × P5,P4 × P8,P5 × P7 ,P5 × P9,P6 × P,P6 × P10 and P7 × P9 under D_3. From the above results the desirable hybrids for SCA effects under two nitrogen levels and three plant densities were P4 × P8, P5 × P7 followed by P2 × P6 and P8 × P10.

The SCA effects under the combination between two nitrogen levels and three plant density and their combined for grain yield (Table 9), showed that the desirable hybrids for SCA effects were ; nine hybrids P1 × P4, P1 × P5, P2 × P6, P2 × P9, P3 × P5, P4 × P8, P5 × P7, P5 × P10 and P7 × P8 under N_1D_1, seven hybrids P1 × P8, P1 × P9, P2 × P6, P2 × P8, P4 × P5, P4 × P8 and P5 × P7 under N_1D_2, eleven hybrids P1 ×P8, P2 × P6, P3 × P4, P4 × P5, P4 × P8, P5 × P7, P5 × P9, P5 × P10, P6 × P9, P7 × P8 and P7 × P10 under N_1D_3, eleven hybrids P1 × P3, P1 × P5, P1 × P9, P2 × P6, P2 × P7, P3 × P5, P3 × P9, P4 × P8, P5 × P9, P6 × P8 and P8 × P10 under N_2D_1 six hybrids P1 × P3, P1 × P5, P2 × P4, P3 × P5, P5 × P7 and P7 × P8 under N_2D_2 and eight hybrids P1 × P3, P1 × P8, P2 × P10, P3 × P8, P4 × P10, P5 × P7, P7 × P9 and P8 × P10 under N_2D_3. Meanwhile, the best hybrids for SCA effects across all environments were P1 × P3, P1× P5, P1 × P8, P2 × P6, P2 × P10, P3 × P5, P4 × P5, P4 × P8, P5 × P7, P5 × P9, P7 × P8 and P8 × P10. These hybrids can be used in maize breeding program.

The non-additive gene action was the main controlling factor in the inheritance for grain yield and it was more affected by environment compared to additive gene action. The best inbred lines for general combining ability were P1, P3, P8 and P10 and the best hybrids for specific combining ability effects were P1×P3, P1×P8, P2×P6, and P8×P10. These hybrids can be upgraded to other stages of evaluation in the maize breeding program, especially for plant density tolerance.

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