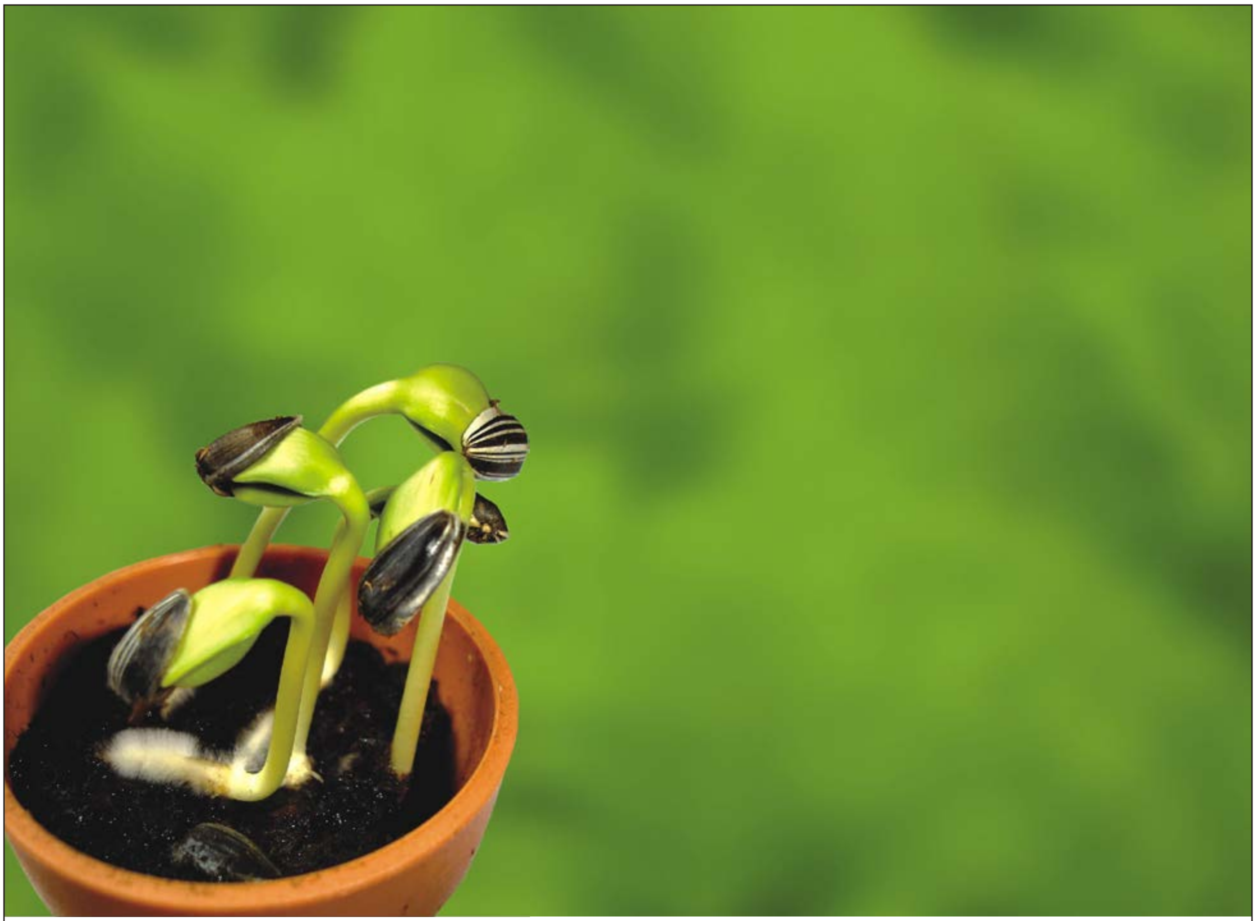

International Journal of Plant Breeding and Genetics

ISSN 1819-3595

Academic
Journals Inc.

www.academicjournals.com

International Journal of Plant Breeding and Genetics 9 (2): 32-43, 2015
ISSN 1819-3595 / DOI: 10.3923/ijpbg.2015.32.43
© 2015 Academic Journals Inc.

Diallel Analysis of Some Yellow Maize Inbred Lines under Low and Normal Nitrogen Levels

Mohamed M. Kamara
Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, 33516, Egypt

ABSTRACT

A half diallel cross among seven yellow maize inbred lines was evaluated under low (60 kg N fed^{-1}) and normal (120 kg N fed^{-1}) nitrogen levels for six quantitative characters i.e., plant height, ear length, ear diameter, number of rows ear^{-1}, number of kernels row^{-1} and grain yield plant^{-1}, to estimate general (GCA) and specific (SCA) combining ability effects and their interactions with nitrogen levels as well as identify the superior inbred lines and crosses. Significant differences were detected between the two nitrogen levels for all the studied traits except ear diameter and number of rows ear^{-1}. Mean squares of crosses and crosses×N interaction were significant for all the studied traits. Both GCA and SCA mean squares were highly significant for all the studied traits under the two nitrogen levels and their combined data. The ratio of GCA/SCA exceeded the unity for plant height, ear diameter, number of rows ear^{-1} and number of kernels row^{-1}, indicating that these traits were mainly controlled by additive gene action. On the contrary, predominance of non-additive gene action chiefly controlled the expression of ear length and grain yield plant^{-1} under both and across nitrogen levels. Significant interaction mean squares between GCA and SCA with nitrogen levels were detected for the most studied traits. Three crosses $P_3\times P_6$, $P_2\times P_6$ and $P_4\times P_7$ at low nitrogen level, four crosses $P_3\times P_6$, $P_4\times P_7$, $P_1\times P_3$ and $P_4\times P_5$ at normal nitrogen level and five crosses $P_3\times P_6$, $P_2\times P_6$, $P_4\times P_7$, $P_1\times P_3$ and $P_4\times P_5$ at the combined data were significantly outyielded the check hybrid SC168. The inbred lines P_3 and P_4 were the best general combiners for ear length, number of rows ear^{-1}, number of kernels row^{-1} and grain yield plant^{-1} under both nitrogen levels and their combined data. Six crosses i.e., $P_2\times P_6$, $P_3\times P_6$, $P_4\times P_5$, $P_4\times P_7$, $P_1\times P_3$ and $P_1\times P_5$ were distinguished specific combiners for grain yield plant^{-1} and most of its components under low and normal nitrogen levels as well as the combined data.

Key words: Maize, GCA, SCA, nitrogen levels

INTRODUCTION

Maize (*Zea mays* L.) is one of the major cereal crops in Egypt and the world, which ranks the third one surpassed only by wheat and rice. One of the major objective of maize breeding program in Egypt is to develop high yielding yellow maize hybrids to activate the national plan for increasing yellow maize production to meet the increasing demand for poultry and animal feeding.

The nature and magnitude of gene action is an important factor in developing an effective breeding program. Combining ability analysis is an important tool to select desirable parents together with the information regarding to the nature and magnitude of gene effects controlling quantitative traits. The diallel cross technique as developed by Sprague and Tatum (1942) and Griffing (1956) provided information on gene action and combining ability of parental lines. The two main genetic parameters of diallel cross analysis are general and specific combining ability (GCA and SCA). The GCA effects are attributed to preponderance of genes with additive effects and SCA indicates predominance of genes with non-additive effects (Falconer, 1981). Several investigators reported that the additive genetic effects were operated in the expression of grain yield (Vacaro *et al.*, 2002; Ojo *et al.*, 2007; Mousa, 2014; Rovaris *et al.*, 2014), plant height (Nigussie and Zelleke, 2001; Abd El-Hadi *et al.*, 2004; Worku *et al.*, 2008) and number of rows ear^{-1} (Saeed *et al.*, 2000; Abuali *et al.*, 2012; El-Badawy, 2013). While, other researchers suggested that the magnitude of non-additive genetic effects represented the major role in the inheritance of grain yield (Bhatnagar *et al.*, 2004; Barakat and Osman, 2008; Gouda *et al.*, 2013) and ear length (Zare *et al.*, 2011; Abdel-Moneam *et al.*, 2014). These differences generally arise due to differences in the genetic materials and the environments under which the experiments were performed.

Combined with the genetic improvement, the use of nitrogen fertilizer and other cultural improvement have contributed to increase the grain yield of maize (Duvick, 2005; Li *et al.*, 2011). Nitrogen is the most important nutritive element for the production of maize as it promotes vegetative growth, maximizing both kernel initiation and kernel set, also it is key in filling the kernel sink (Below, 1997). Modern maize hybrids require high doses of nitrogen fertilizer to express full yield potential. However, besides increasing the cost of cultivation, high nitrogen fertilization has adverse effects on the ground water, atmosphere and other components of the ecosystem (Socolow, 1999; Bowman *et al.*, 2008). Most Egyptian farmers use low nitrogen fertilizer rates because of high price ratio between fertilizer and grain. Limited availability of nitrogen fertilizers and low purchasing power of farmers continued to be an important yield limiting factor in farmer's field (Al-Naggar *et al.*, 2015). Breeding programs should pay attention to develop maize hybrids with high performance under variable nitrogen levels that will be of economic benefit to farmers who cannot afford to spend money for purchasing the recommended amount of nitrogen fertilizer, also will help to reduce environmental pollution associated with excessive inputs of nitrogen fertilizers, for a sustainable and environment friendly production system. The objectives of this study were to (1) Estimate general (GCA) and specific (SCA) combining ability effects and their interactions with nitrogen levels (2) Identify the promising inbred lines and crosses under low and normal nitrogen levels to be used in maize breeding programs.

MATERIALS AND METHODS

Plant materials: Seven yellow maize inbred lines were used as parents in this study i.e., P_1 (Inb. 176), P_2 (Inb. 185), P_3 (Inb. 200), P_4 (Inb. 205), P_5 (Inb. 213), P_6 (Inb. 247) and P_7 (Inb. 209). These inbred lines were obtained from Maize Research Department, Field Crops Research Institution (FCRI), Agricultural Research Center (ARC), Egypt.

Field experiments: In 2012 growing season, a half diallel cross among the seven inbred lines were made by the hand method at the Experimental Farm of the Faculty of Agriculture, Kafrelsheikh University, Egypt. In 2013 growing season, the resulted 21 F_1 hybrids and the commercial check hybrid SC168 were evaluated in two separate experiments under two different nitrogen levels i.e., 60 kg N fed^{-1} (low-N) and 120 kg N fed^{-1} (Normal or recommended). A randomized complete block design with three replications was used for each experiment. Each plot consisted of two rows, 6 m long and 70 cm width. Planting was made in hills spaced at 25 cm with three kernels per hill on one side of the row. The seedlings were thinned to one plant per hill after 21 days from planting. Each experiment was hoed twice, before first and second irrigations. Phosphorus in the form of calcium super phosphate (15.5% P_2O_5) at a rate of 200 kg fed^{-1} was added to the soil during seedbed preparation and potassium sulphate (48% K_2O) at a level of 50 kg fed^{-1} was applied after thinning. Moreover, nitrogen in the form of Urea (46% N) at the studied levels (60 and 120 kg N fed^{-1}) was added in two equal split doses, before the first and the second irrigation. Other agriculture practices were applied as recommended. Data were taken for plant height (cm), ear length (cm), ear diameter (cm), number of rows ear^{-1}, number of kernels row^{-1} and grain yield plant^{-1} (g) which was adjusted to 15.5% moisture.

Statistical analysis: The obtained data were statistically analyzed for analysis of variance by using computer statistical program MSTAT-C. General and specific combining ability were estimated according to Griffing (1956) diallel cross analysis designated as method-4, model-1. The combined analysis of the two experiments was carried out whenever homogeneity of variance was detected (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Analysis of variance for all the studied traits under both nitrogen levels and their combined data are presented in Table 1. Significant differences were detected between the two nitrogen levels

Table 1: Mean squares from ordinary analysis of variance and combining ability for all the studied traits under low and normal nitrogen levels as well as the combined data

	d.f		Plant height (cm)			Ear length (cm)			Ear diameter (cm)		
S.O.V	Single	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
Nitrogen (N)	-	1	-	-	18008.4*	-	-	208.0*	-	-	7.65
Rep/N	-	4	-	-	1372.6	-	-	24.01	-	-	6.17
Crosses (C)	20	20	1236.11**	1719.98**	2794.40**	17.93**	19.65**	36.10**	0.51**	0.44**	0.82**
GCA	6	6	1409.69**	2696.31**	3962.07**	13.58**	15.22**	28.12**	1.15**	0.61**	1.62**
SCA	14	14	1165.81**	1301.55**	2296.52**	19.80**	21.55**	39.52**	0.23**	0.37**	0.48**
C×N	-	20	-	-	161.69**	-	-	1.49*	-	-	0.13**
GCA×N	-	6	-	-	143.94*	-	-	0.68	-	-	0.14*
SCA×N	-	14	-	-	170.84**	-	-	1.83*	-	-	0.12*
Error	40	80	61.19	56.51	58.85	0.79	0.84	0.82	0.05	0.07	0.06
GCA/SCA			1.21	2.07	1.73	0.69	0.71	0.71	4.94	1.64	3.37
GCA×N/SCA×N			-	-	0.84	-	-	0.37	-	-	1.17
	d.f		No. of rows ear^{-1}			No. of kernels row^{-1}			Grain yield plant^{-1} (g)		
S.O.V	Single	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
Nitrogen (N)	-	1	-	-	65.51	-	-	649.5*	-	-	31596.4**
Rep/N	-	4	-	-	22.02	-	-	18.07	-	-	341.0
Crosses (C)	20	20	3.55**	7.16**	9.43**	50.19**	30.58**	75.17**	1319.5**	1884.0**	3005.7**
GCA	6	6	6.82**	14.57**	19.60**	56.77**	34.31**	87.93**	799.43**	1098.28**	1567.99**
SCA	14	14	2.15**	3.99**	5.07**	47.37**	28.98**	69.71**	1542.4**	2220.72**	3621.86**
C×N	-	20	-	-	1.29*	-	-	5.59*	-	-	197.80*
GCA×N	-	6	-	-	1.78*	-	-	3.15	-	-	329.72**
SCA×N	-	14	-	-	1.07	-	-	6.64**	-	-	141.26
Error	40	80	0.84	0.60	0.72	2.50	3.08	2.79	95.89	112.91	104.40
GCA/SCA			3.16	3.65	3.87	1.20	1.18	1.26	0.52	0.49	0.43
GCA×N/SCA×N			-	-	1.66	-		0.47	-	-	2.33

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

for all the studied traits except ear diameter and number of rows ear^{-1}. Crosses mean squares were highly significant for all the studied under both nitrogen levels and their combined data, indicating the existence of substantial genetic variability among the studied crosses. Significant interaction mean squares between crosses and nitrogen levels (C×N) were observed for all the studied traits. This indicates that, these crosses behaved somewhat differently from nitrogen level to another. These results are in accordance with those obtained by Mosa *et al.* (2010), El-Badawy (2013), Katta *et al.* (2013) and Abd El-Aty *et al.* (2014).

Mean squares due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the studied traits under both nitrogen levels and their combined data, suggesting that both additive and non-additive genetic effects were involved in the inheritance of these traits. When both GCA and SCA mean squares are significant, one may ask which type and or types of gene action are important in determining the performance of single cross progeny. To overcome such situation the size of mean squares can be used to assume the relative importance of GCA and SCA mean squares which were highly significant. Hence, GCA/SCA ratio was used as measure to reveal the nature of genetic variance involved. GCA/SCA ratio was more than unity for plant height, ear diameter, number of rows ear^{-1} and number of kernels row^{-1} under both and across nitrogen levels, indicating that these traits were mainly controlled by additive gene action. These results are in general agreement with those previously reported by Vacaro *et al.* (2002), Nigussie and Zelleke (2001), Abd El-Hadi *et al.* (2004), Worku *et al.* (2008), Mosa (2010) and Rovaris *et al.* (2014) for plant height, Saeed *et al.* (2000), Abuali *et al.* (2012) and El-Badawy (2013) for number of rows ear^{-1} and Mosa (2003), Katta *et al.* (2007) and Motawei and Mosa (2009) for ear diameter and number of kernels row^{-1}.

On the other hand, GCA/SCA ratio was less than unity for ear length and grain yield plant^{-1} under both nitrogen levels and their combined data, indicating the predominance of non-additive gene action in controlling the inheritance of these traits. These results are in agreement with reports of other researchers about the predominance of non-additive genetic effects for ear length (Vidal-Martinez *et al.*, 2001; Rezaei and Roohi, 2004; Zare *et al.*, 2011; Gouda *et al.*, 2013) and grain yield plant-1 (Bhatnagar *et al.*, 2004; Katta *et al.*, 2007; Barakat and Osman, 2008; Irshad-Ul-Haq *et al.*, 2010; El-Badawy, 2013; Abdel-Moneam *et al.*, 2014).

Mean squares due to the interactions of GCA and SCA with nitrogen levels were significant for all the studied traits except GCA×N for ear length and number of kernels row^{-1} and SCA×N for number of rows ear^{-1} and grain yield plant^{-1}. Such results showed that the magnitude of additive and no-additive types of gene action varied from nitrogen level to another. Mean squares due to GCA×N were higher than those due to SCA×N and GCA×N/SCA×N ratio was more than unity for ear diameter, number of rows ear^{-1} and grain yield plant^{-1}. Such results clarified that the additive genetic effects were more influenced by nitrogen levels than the non-additive genetic effects for these traits. Conversely, the non-additive genetic effects were more affected by change in nitrogen levels than the additive genetic effects for plant height, ear length and number of kernels row^{-1}. These results are in agreement with those obtained by Abd El-Aty (2007) and Katta *et al.* (2013) for plant height and number of kernels row^{-1}.

Mean performances: Conspicuously, Table 2 shows that the overall mean values of the crosses under normal nitrogen level were higher than those under low nitrogen level for all the studied traits. The increase of plant height under normal nitrogen level might be due to the positive effect of nitrogen element on plant growth that leads to a progressive increase in internodes length and consequently plant height (Siddiqui *et al*., 2006; Kaur *et al*., 2012). The improved growth of maize plants under normal nitrogen level compared to those under low nitrogen level may account for the superiority of all yield components and ultimately the increase of grain yield plant^{-1}. These results are in agreement with those obtained by Zaidi *et al*. (2003), Medici *et al*. (2004) and Kamara *et al*. (2014).

Five crosses $P_1 \times P_6$, $P_6 \times P_7$, $P_1 \times P_7$, $P_5 \times P_7$ and $P_1 \times P_3$ under both nitrogen levels and their combined data had significantly decreased values than the check hybrid SC168 for plant height. Also, the cross $P_3 \times P_5$ under low nitrogen level, the cross $P_2 \times P_5$ under low nitrogen level and the combined data and the cross $P_1 \times P_5$ under normal nitrogen level were significantly shorter than the check hybrid SC168. The short stalks are preferable in maize for decreases lodging percentage and thus increased yield potential. Five crosses $P_3 \times P_6$, $P_3 \times P_4$, $P_4 \times P_5$, $P_2 \times P_6$ and $P_1 \times P_4$ under both nitrogen levels and their combined data were significantly higher than check hybrid SC168 for ear length. Concerning, ear diameter the crosses $P_4 \times P_7$ and $P_6 \times P_7$ under both nitrogen levels and the combined data, the crosses $P_3 \times P_7$ and $P_2 \times P_7$ under low nitrogen level, the cross $P_2 \times P_6$ under low nitrogen level and the combined data and the cross $P_1 \times P_3$ under normal nitrogen level and the combined data were significantly surpassed the check hybrid SC168. Four crosses $P_4 \times P_7$, $P_3 \times P_7$, $P_3 \times P_4$ and $P_2 \times P_7$ under

Table 2: Mean performance of the 21 single crosses and check hybrid SC168 for all the studied traits under low, normal nitrogen levels and their combined data

	Plant height (cm)			Ear length (cm)			Ear diameter (cm)		
Crosses	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
$P_1 \times P_2$	235.00	263.00	250.33	17.50	19.30	18.40	3.38	4.27	3.83
$P_1 \times P_3$	226.67	240.33	233.50	18.30	20.20	19.25	4.15	5.53	4.84
$P_1 \times P_4$	270.50	302.00	286.25	19.47	22.67	21.07	4.01	4.43	4.22
$P_1 \times P_5$	239.00	247.00	243.00	16.50	18.30	17.40	4.03	4.45	4.24
$P_1 \times P_6$	213.33	232.67	223.00	13.60	17.00	15.30	3.53	4.43	3.98
$P_1 \times P_7$	221.00	235.80	228.40	13.80	16.75	15.28	4.08	4.29	4.19
$P_2 \times P_3$	240.00	252.00	246.00	17.40	19.50	18.45	4.44	4.75	4.60
$P_2 \times P_4$	238.00	256.67	247.33	16.40	19.00	17.70	4.13	4.65	4.39
$P_2 \times P_5$	223.00	255.50	239.25	14.40	17.90	16.15	3.98	4.21	4.10
$P_2 \times P_6$	249.00	268.33	258.67	19.80	22.55	21.18	4.88	5.02	4.95
$P_2 \times P_7$	234.00	252.00	243.00	17.80	18.78	18.29	4.60	4.99	4.80
$P_3 \times P_4$	255.00	298.00	276.50	20.30	23.50	21.90	4.54	5.00	4.77
$P_3 \times P_5$	226.83	266.67	246.75	14.30	18.38	16.34	4.55	4.85	4.70
$P_3 \times P_6$	285.00	316.67	300.83	21.20	23.50	22.35	4.45	5.00	4.73
$P_3 \times P_7$	265.00	278.00	271.50	18.30	20.20	19.25	4.76	4.85	4.81
$P_4 \times P_5$	275.00	295.00	285.00	19.40	23.90	21.65	4.53	4.98	4.76
$P_4 \times P_6$	235.00	261.67	248.33	14.00	15.20	14.60	4.02	4.55	4.29
$P_4 \times P_7$	243.00	288.00	265.50	17.00	20.00	18.50	4.95	5.50	5.23
$P_5 \times P_6$	233.33	251.33	242.33	13.00	15.00	14.00	4.02	4.55	4.29
$P_5 \times P_7$	214.17	243.78	228.97	19.20	20.20	19.70	4.57	4.95	4.76
$P_6 \times P_7$	215.00	237.20	226.10	16.20	20.00	18.10	4.60	5.30	4.95
Check SC168	240.00	261.00	250.50	17.90	21.00	19.45	4.23	4.85	4.54
Overall mean	239.86	263.76	251.87	17.08	19.67	18.38	4.29	4.79	4.54
LSD (5%)	12.91	12.40	8.81	1.47	1.52	1.04	0.37	0.44	0.28
LSD (1%)	17.27	16.60	11.68	1.97	2.03	1.38	0.49	0.59	0.37

Table 2: Continue

	No. of rows ear^{-1}			No. of kernels row^{-1}			Grain yield plant^{-1} (g)		
Crosses	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
$P_1 \times P_2$	13.55	15.70	14.63	34.50	39.40	36.95	115.62	155.17	135.39
$P_1 \times P_3$	15.13	19.30	17.22	39.80	43.00	41.40	149.57	194.44	172.01
$P_1 \times P_4$	14.85	15.50	15.18	39.75	41.85	40.80	132.32	176.09	154.20
$P_1 \times P_5$	14.80	15.00	14.90	38.50	44.10	41.30	126.00	169.71	147.86
$P_1 \times P_6$	12.70	14.60	13.65	32.00	38.50	35.25	94.03	127.36	110.70
$P_1 \times P_7$	13.50	14.33	13.92	34.50	37.30	35.90	108.09	136.11	122.10
$P_2 \times P_3$	14.70	15.80	15.25	41.80	46.80	44.30	128.63	145.83	137.23
$P_2 \times P_4$	14.45	15.55	15.00	36.50	43.00	39.75	120.17	142.98	131.57
$P_2 \times P_5$	14.00	15.33	14.67	34.33	36.80	35.57	104.13	126.00	115.06
$P_2 \times P_6$	14.47	14.60	14.53	43.80	45.50	44.65	160.53	188.61	174.57
$P_2 \times P_7$	15.60	17.00	16.30	37.00	42.50	39.75	107.68	136.85	122.27
$P_3 \times P_4$	15.60	17.97	16.78	39.80	44.00	41.90	128.33	169.17	148.75
$P_3 \times P_5$	14.00	16.73	15.37	36.50	41.50	39.00	108.85	127.46	118.16
$P_3 \times P_6$	13.66	15.50	14.58	44.33	47.20	45.77	166.25	198.33	182.29
$P_3 \times P_7$	16.07	17.50	16.78	39.98	42.50	41.24	132.22	149.33	140.78
$P_4 \times P_5$	14.70	15.65	15.18	43.00	47.00	45.00	142.92	193.47	168.20
$P_4 \times P_6$	14.50	15.33	14.92	38.00	41.50	39.75	101.56	131.68	116.62
$P_4 \times P_7$	16.83	19.00	17.92	41.00	46.00	43.50	153.61	195.42	174.51
$P_5 \times P_6$	13.20	14.00	13.60	30.20	38.00	34.10	94.79	143.62	119.21
$P_5 \times P_7$	13.67	14.63	14.15	38.00	43.00	40.50	126.78	142.63	134.70
$P_6 \times P_7$	12.47	13.70	13.08	30.30	39.50	34.90	137.28	154.20	145.74
Check SC168	13.80	14.83	14.32	40.00	44.00	42.00	135.16	175.58	155.37
Overall mean	14.38	15.80	15.09	37.89	42.41	40.15	126.11	158.18	142.15
LSD (5%)	1.51	1.27	0.97	2.61	2.89	1.92	16.16	17.53	11.73
LSD (1%)	2.02	1.71	1.29	3.49	3.87	2.54	21.62	23.46	15.56

the two nitrogen levels and the combined data and two crosses $P_1 \times P_3$ and $P_3 \times P_5$ under normal nitrogen level and the combined data had significantly increased values compared to the check hybrid SC168 for number of rows ear^{-1}. The crosses $P_3 \times P_6$ and $P_4 \times P_5$ under both nitrogen levels and the combined data, $P_2 \times P_6$ under low nitrogen level and the combined data and $P_2 \times P_3$ under the combined data exhibited significantly increased values compared to the check hybrid SC168 for number of kernels row^{-1}. Concerning grain yield plant^{-1} three crosses $P_3 \times P_6$, $P_2 \times P_6$ and $P_4 \times P_7$ at low nitrogen level, four crosses $P_3 \times P_6$, $P_4 \times P_7$, $P_1 \times P_3$ and $P_4 \times P_5$ at normal nitrogen and five crosses $P_3 \times P_6$, $P_2 \times P_6$, $P_4 \times P_7$, $P_1 \times P_3$ and $P_4 \times P_5$ at the combined data were significantly outyielded the check hybrid SC168. These crosses exhibited significant increase in one or more of traits contributing to grain yield plant^{-1}. Hence it could be concluded that these crosses offer possibility for improving grain yield of maize. The fluctuation of the hybrids performance from nitrogen level to another was detected for most traits. These results would be due to significant interaction between crosses and nitrogen levels.

General combining ability effects (GCA): Identification of parents for improvement of trait in question necessitates the assessment of general combining ability effects. Estimates of GCA effects of the seven inbred lines under low and normal nitrogen levels as well as the combined data for all the studied traits are shown in Table 3. High positive values of GCA effects would be of interest for all studied traits in question except plant height, where high negative values would be useful for plant breeder point of view. Obviously, the results showed that the inbred lines P_1, P_7, P_2 and P_5 had significant or highly significant negative GCA effects for plant height under both nitrogen levels and their combined data, indicating that these inbred lines could be considered as good combiners for developing short stalk genotypes. On the other hand, the inbred lines P_3 and P_4 exhibited significant or highly significant positive GCA effects and considered as a good combiners for ear length, number of rows ear^{-1}, number of kernels row^{-1} and grain yield plant^{-1} under both nitrogen levels and the combined data. While, the inbred lines P_7 and P_3 were the best general combiners for ear diameter under both and across nitrogen levels. These results indicated that these inbred lines possess favorable genes and the improvement in yield may be attained if they are used in hybridization program.

Specific combining ability effects (SCA): Estimates of SCA effects of the 21 crosses for all the studied traits under both nitrogen levels and their combined data are given in Table 4. For plant height nine, six and nine crosses exhibited significant or highly significant negative SCA effects

Table 3: General combining ability effects of the seven inbred lines under low and normal nitrogen levels as well as the combined data for all the studied traits

	Plant height (cm)			Ear length (cm)			Ear diameter (cm)		
Inbred line	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
P_1	-6.72**	-12.50**	-9.61**	-0.62**	-0.69**	-0.65**	-0.52**	-0.26**	-0.39**
P_2	-4.02*	-7.16**	-5.59**	0.21	-0.13	0.04	-0.07	-0.17**	-0.12**
P_3	11.88**	13.67**	12.78**	1.51**	1.52**	1.52**	0.22**	0.25**	0.24**
P_4	15.48**	23.60**	19.54**	0.86**	1.32**	1.09**	0.08	0.08	0.080
P_5	-5.55**	-4.81*	-5.18**	-1.09**	-0.80**	-0.94**	-0.02	-0.15*	-0.083*
P_6	-1.69	-3.09	-2.39	-0.89**	-0.88**	-0.89**	-0.05	0.02	-0.02
P_7	-9.39**	-9.71**	-9.55**	0.01	-0.35	-0.17	0.36**	0.23**	0.29**
LSD gi (5%)	3.78	3.63	2.58	0.43	0.44	0.30	0.11	0.13	0.083
LSD gi (1%)	5.06	4.86	3.42	0.58	0.59	0.40	0.14	0.17	0.11
LSD gi-gj (5%)	5.77	5.55	3.94	0.66	0.68	0.46	0.16	0.20	0.13
LSD gi-gj (1%)	7.72	7.42	5.22	0.88	0.91	0.62	0.22	0.27	0.17

	No. of rows ear^{-1}			No. of kernels row^{-1}			Grain yield plant^{-1} (g)		
Inbred line	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
P_1	-0.38	-0.13	-0.25	-1.54**	-1.97**	-1.75**	-5.69*	2.95	-1.37
P_2	0.07	-0.22	-0.07	0.24	0.00	0.12	-3.47	-9.74**	-6.60**
P_3	0.55*	1.55**	1.05**	3.09**	2.20**	2.65**	11.95**	8.09**	10.02**
P_4	0.90**	0.79**	0.85**	2.26**	1.87**	2.07**	4.96*	12.93**	8.95**
P_5	-0.41	-0.74**	-0.58**	-1.24**	-0.72	-0.98**	-10.13**	-8.25**	-9.19**
P_6	-1.08**	-1.47**	-1.28**	-1.62**	-0.76	-1.19**	0.07	-0.07	0.00
P_7	0.34	0.22	0.28	-1.19**	-0.64	-0.91**	2.31	-5.92*	-1.80
LSD gi (5%)	0.44	0.37	0.29	0.76	0.85	0.56	4.73	5.13	3.44
LSD gi (1%)	0.59	0.50	0.38	1.02	1.13	0.74	6.33	6.87	4.56
LSD gi-gj (5%)	0.68	0.57	0.44	1.17	1.29	0.86	7.23	7.84	5.25
LSD gi-gj (1%)	0.91	0.76	0.58	1.56	1.73	1.14	9.67	10.49	6.96

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

under low, normal nitrogen levels and the combined data, respectively. The crosses $P_1\times P_3$, $P_4\times P_6$, $P_2\times P_4$, $P_1\times P_6$, $P_6\times P_7$ and $P_2\times P_3$ gave the highest desirable SCA effects under both nitrogen levels and their combined data, indicating that these crosses were the best combinations for short plants. With regard to ear length, eight, seven and nine crosses expressed significant or highly significant positive SCA effects under low, normal nitrogen levels and the combined data, respectively. Also, the crosses $P_2\times P_6$, $P_3\times P_6$, $P_4\times P_5$, $P_5\times P_7$, $P_3\times P_4$ and $P_1\times P_4$ exhibited the best SCA effects for this trait under the two nitrogen levels as well as the combined data. As for ear diameter three, five and five crosses possessed significant or highly significant positive SCA effects under low, normal nitrogen levels and the combined data, respectively. The crosses $P_2\times P_6$ and $P_4\times P_7$ recorded the highest desirable SCA effects for this trait under both nitrogen levels and the combined data. Concerning, number of rows ear^{-1} three, three and five crosses exhibited significant or highly significant positive SCA effects under low, normal nitrogen levels and the combined data, respectively. In addition, the best SCA effects was detected by the cross $P_4\times P_7$ under both nitrogen levels and the combined data. With regard to number of kernels row^{-1} six, seven and seven crosses expressed significant or highly significant positive SCA effects under low, normal nitrogen levels and the combined data,

Table 4: Specific combining ability effects of the 21 crosses under both nitrogen levels and their combined data for all the studied traits

	Plant height (cm)			Ear length (cm)			Ear diameter (cm)		
Crosses	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
$P_1\times P_2$	5.89	18.78**	12.33**	0.86*	0.51	0.69*	-0.33**	-0.09	-0.21*
$P_1\times P_3$	-18.34**	-24.72**	-21.53**	0.36	-0.24	0.06	0.15	0.76**	0.46**
$P_1\times P_4$	21.89**	27.01**	24.45**	2.18**	2.43**	2.30**	0.15	-0.17	-0.01
$P_1\times P_5$	11.42**	0.42	5.92*	1.16**	0.18	0.67*	0.27*	0.07	0.17*
$P_1\times P_6$	-18.11**	-15.63**	-16.87**	-1.94**	-1.04*	-1.49**	-0.19	-0.12	-0.16*
$P_1\times P_7$	-2.74	-5.88	-4.31	-2.64**	-1.82**	-2.23**	-0.05	-0.46**	-0.26**
$P_2\times P_3$	-7.71*	-18.39**	-13.05**	-1.36**	-1.51**	-1.43**	-0.01	-0.12	-0.06
$P_2\times P_4$	-13.31**	-23.66**	-18.49**	-1.72**	-1.80**	-1.76**	-0.17	-0.05	-0.11
$P_2\times P_5$	-7.28	3.58	-1.85	-1.76**	-0.79	-1.27**	-0.22*	-0.26*	-0.24**
$P_2\times P_6$	14.86**	14.70**	14.78**	3.44**	3.95**	3.69**	0.71**	0.38**	0.54**
$P_2\times P_7$	7.56*	4.98	6.27*	0.54	-0.36	0.09	0.02	0.14	0.08
$P_3\times P_4$	-12.21**	-3.16	-7.69**	0.88*	1.05*	0.97**	-0.06	-0.12	-0.09
$P_3\times P_5$	-19.34**	-6.08	-12.71**	-3.16**	-1.96**	-2.56**	0.05	-0.04	0.00
$P_3\times P_6$	34.96**	42.20**	38.58**	3.54**	3.25**	3.39**	-0.01	-0.06	-0.04
$P_3\times P_7$	22.66**	10.15**	16.40**	-0.26	-0.59	-0.42	-0.12	-0.42**	-0.27**
$P_4\times P_5$	25.22**	12.32**	18.77**	2.58**	3.77**	3.18**	0.17	0.26*	0.22**
$P_4\times P_6$	-18.64**	-22.73**	-20.69**	-3.02**	-4.85**	-3.93**	-0.30**	-0.34**	-0.32**
$P_4\times P_7$	-2.94	10.22**	3.64	-0.92*	-0.58	-0.75*	0.21*	0.41**	0.31**
$P_5\times P_6$	0.72	-4.66	-1.97	-2.06**	-2.93**	-2.50**	-0.20	-0.11	-0.16*
$P_5\times P_7$	-10.74**	-5.59	-8.17**	3.24**	1.73**	2.49**	-0.07	0.08	0.01
$P_6\times P_7$	-13.78**	-13.89**	-13.83**	0.04	1.62**	0.83**	0.00	0.26*	0.13
LSD (sij) (5%)	7.45	7.16	5.09	0.85	0.88	0.60	0.21	0.26	0.16
LSD (sij) (1%)	9.97	9.58	6.75	1.13	1.17	0.80	0.28	0.34	0.22
LSD (sij-sik) (5%)	11.54	11.09	7.88	1.31	1.36	0.93	0.33	0.40	0.25
LSD (sij-sik) (1%)	15.45	14.84	10.45	1.76	1.81	1.23	0.44	0.53	0.34
LSD (sij-skl) (5%)	10.00	9.61	6.82	1.14	1.17	0.80	0.28	0.34	0.22
LSD (sij-skl) (1%)	13.36	12.86	9.05	1.52	1.57	1.07	0.38	0.46	0.29

Table 4: Continue

	No. of rows ear^{-1}			No. of kernels row^{-1}			Grain yield plant^{-1} (g)		
Cross	Low-N	Normal	Comb.	Low-N	Normal	Comb.	Low-N	Normal	Comb.
$P_1\times P_2$	-0.55	0.20	-0.17	-1.99*	-0.97	-1.48**	-0.90	4.60	1.85
$P_1\times P_3$	0.56	2.04**	1.30**	0.45	0.43	0.44	17.63**	26.05**	21.84**
$P_1\times P_4$	-0.08	-1.00**	-0.54	1.24	-0.39	0.42	7.37	2.85	5.11
$P_1\times P_5$	1.18**	0.03	0.60*	3.49**	4.45**	3.97**	16.14**	17.65**	16.90**
$P_1\times P_6$	-0.24	0.35	0.05	-2.63**	-1.11	-1.87**	-26.03**	-32.88**	-29.45**
$P_1\times P_7$	-0.87*	-1.61**	-1.24**	-0.56	-2.43**	-1.49**	-14.21**	-18.28**	-16.24**
$P_2\times P_3$	-0.32	-1.37**	-0.85**	0.68	2.26**	1.47**	-5.54	-9.87	-7.70*
$P_2\times P_4$	-0.93*	-0.86*	-0.89**	-3.79**	-1.21	-2.50**	-7.01	-17.57**	-12.29**
$P_2\times P_5$	-0.06	0.45	0.19	-2.46**	-4.82**	-3.64**	-7.96	-13.37*	-10.66**
$P_2\times P_6$	1.08*	0.44	0.76**	7.39**	3.92**	5.66**	38.25**	41.06**	39.66**
$P_2\times P_7$	0.78	1.15**	0.97**	0.16	0.80	0.48	-16.84**	-4.85	-10.85**
$P_3\times P_4$	-0.26	-0.21	-0.23	-3.35**	-2.41**	-2.88**	-14.26**	-9.21	-11.74**
$P_3\times P_5$	-0.54	0.09	-0.23	-3.14**	-2.32**	-2.73**	-18.66**	-29.73**	-24.20**
$P_3\times P_6$	-0.21	-0.42	-0.32	5.07**	3.42**	4.25**	28.55**	32.96**	30.75**
$P_3\times P_7$	0.77	-0.11	0.33	0.29	-1.40	-0.55	-7.72	-10.19*	-8.96*
$P_4\times P_5$	-0.20	-0.24	-0.22	4.19**	3.51**	3.85**	22.40**	31.43**	26.92**
$P_4\times P_6$	0.28	0.17	0.22	-0.43	-1.95*	-1.19*	-29.15**	-38.54**	-33.85**
$P_4\times P_7$	1.18**	2.15**	1.67**	2.14**	2.43**	2.29**	20.65**	31.05**	25.85**
$P_5\times P_6$	0.29	0.37	0.33	-4.73**	-2.86**	-3.79**	-20.83**	-5.42	-13.13**
$P_5\times P_7$	-0.67	-0.69	-0.68*	2.64**	2.02*	2.33**	8.91	-0.56	4.17
$P_6\times P_7$	-1.20**	-0.90*	-1.05**	-4.68**	-1.44	-3.06**	9.21	2.83	6.02
LSD (sij) (5%)	0.87	0.74	0.56	1.51	1.67	1.11	9.33	10.12	6.77
LSD (sij) (1%)	1.17	0.98	0.75	2.02	2.24	1.47	12.48	13.54	8.98
LSD (sij-sik) (5%)	1.35	1.14	0.87	2.33	2.59	1.72	14.45	15.68	10.49
LSD (sij-sik) (1%)	1.81	1.53	1.15	3.12	3.46	2.28	19.34	20.98	13.92
LSD (sij-skl) (5%)	1.17	0.99	0.75	2.02	2.24	1.49	12.52	13.58	9.09
LSD (sij-skl) (1%)	1.57	1.32	1.00	2.70	3.00	1.97	16.72	18.17	12.05

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

respectively. Also, the results revealed that the crosses $P_2\times P_6$, $P_3\times P_6$, $P_1\times P_5$, $P_4\times P_5$, $P_5\times P_7$ and $P_4\times P_7$ recorded the highest desirable SCA effects for this trait under both nitrogen levels and their combined data. For grain yield plant^{-1} six crosses i.e., $P_2\times P_6$, $P_3\times P_6$, $P_4\times P_5$, $P_4\times P_7$, $P_1\times P_3$ and $P_1\times P_5$ had significant or highly significant positive SCA effects under both nitrogen levels and their combined data. It could be concluded that the previous crosses seemed to be the best combinations, where they had significant SCA effects for grain yield plant^{-1} as well as most of the yield components traits. Hence, these crosses could be selected and used in hybridization programs for improving grain yield. These results are in general agreement with those previously reported by Motawei (2011), Abuali *et al.* (2012), Katta *et al.* (2013), Mousa (2014) and Rovaris *et al.* (2014) where they observed significant positive or negative SCA effects for these traits in their respective studies.

REFERENCES

Abd El-Aty, M.S., 2007. Diallel analysis of some quantitative traits in seven white inbred lines of maize under three nitrogen levels. J. Agric. Res. Kafr El-Sheikh Univ., 33: 551-575.

Abd El-Aty, M.S., M.A. El-Hity, H.E. Mosa and M.A.A. Hassan, 2014. Combining ability analysis in yellow maize under different planting dates and nitrogen rates. Jordan J. Agric. Sci., 10: 237-251.

Abd El-Hadi, A.H., Z.A. Kosba, F.A. El-Zeir and A.E. Abo-Ahmed, 2004. Partial diallel crosses and heterosis in maize (*Zea mays* L.). Zagazig J. Agric. Res., 31: 2187-2206.

Abdel-Moneam, M.A., M.S. Sultan, S.M.G. Salama and A.M. El Oraby, 2014. Evaluation of combining ability and heterosis for yield and its components traits of five maize inbreds under normal and stress nitrogen fertilization. Asian J. Crop Sci., 6: 142-149.

Abuali, A.I., A.A. Abdelmulla, M.M. Khalafalla, A.E. Idris and A.M. Osman, 2012. Combining ability and heterosis for yield and yield components in maize (*Zea mays* L.). Aust. J. Basic Applied Sci., 6: 36-41.

Al-Naggar, A.M.M., R. Shabana, M.M.M. Atta and T.H. Al-Khalil, 2015. Regression of grain yield of maize inbred lines and their diallel crosses on elevated levels of soil-nitrogen. Int. J. Plant Soil Sci., 4: 499-512.

Barakat, A.A. and M.M.A. Osman, 2008. Evaluation of some newly developed yellow maize inbred lines for combining ability in two locations. J. Agric. Sci. Mansoura Univ., 33: 4667-4679.

Below, F.E., 1997. Growth and productivity of maize under nitrogen stress. Proceedings of the Symposium on Developing Drought and Low N Tolerant Maize, March 25-29, 1996, Mexico, pp: 235-240.

Bhatnagar, S., F.J. Betran and L.W. Rooney, 2004. Combining abilities of quality protein maize inbreds. Crop Sci., 44: 1997-2005.

Bowman, W.D., C.C. Cleveland, L. Halada, J. Hresko and J.S. Baron, 2008. Negative impact of nitrogen deposition on soil buffering capacity. Nat. Geosci., 1: 767-770.

Duvick, N.D., 2005. Genetic progress in yield of United States maize (*Zea mays* L.). Maidica, 50: 193-202.

El-Badawy, M.E.M., 2013. Heterosis and combining ability in maize using diallel crosses among seven new inbred lines. Asian J. Crop Sci., 5: 1-13.

Falconer, D.C., 1981. An Introduction to Quantitative Genetics. 2nd Edn., Longman, New York, USA., pp: 67-68.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons, New York, USA., ISBN-13: 9780471870920, Pages: 680.

Gouda, R.K., U. Kage, H.C. Lohithaswa, B.G. Shekara and D. Shobha, 2013. Combining ability studies in maize (*Zea mays* L.). Mol. Plant Breed., 3: 116-127.

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

Irshad-Ul-Haq, M., S.U. Ajmal, M. Munir and M. Gulfaraz, 2010. Gene action studies of different quantitative traits in maize. Pak. J. Bot., 42: 1021-1030.

Kamara, M.M., I.S. El-Degwy and H. Koyama, 2014. Estimation combining ability of some maize inbred lines using line×tester mating design under two nitrogen levels. Aust. J. Crop Sci., 8: 1336-1342.

Katta, Y.S., M.S.M. Abd El-Aty, M.A. El-Hity and M.M. Karmara, 2007. Estimate of heterosis and combining ability of some white inbred lines of maize (*Zea mays* L.). J. Agric. Sci. Mansoura Univ., 32: 7077-7088.

Katta, Y.S., M.M. Kamara, M.A. El-Hity and H. Koyama, 2013. Combining ability for some growthing and yielding traits in maize under two nitrogen levels. Egypt. J. Plant. Breed., 17: 331-345.

Kaur, A., S. Bedi, G. Gill and M. Kumar, 2012. Effect of nitrogen fertilizers on radiation use efficiency, crop growth and yield in some maize (*Zea mays* L.) genotypes. Maydica, 57: 75-82.

Li, L., T. Wegenast, H. Li, B.S. Dhillon and C.F.H. Longin *et al*., 2011. Estimation of quantitative genetic and stability parameters in maize under high and low N levels. Maydica, 56: 25-34.

Medici, L.O., M.B. Pereira, P.J. Lea and R.A. Azevedo, 2004. Diallel analysis of maize lines with contrasting responses to applied nitrogen. J. Agric. Sci., 142: 535-541.

Mosa, H.E., 2003. Combining ability of eight yellow maize (*Zea mays* L.) inbred lines for different characters in diallel crosses. J. Agric. Res. Tanta Univ., 31: 604-614.

Mosa, H.E., 2010. Diallel analysis of nine yellow maize inbred lines. Egypt. J. Plant Breed., 14: 37-47.

Mosa, H.E., A.A. Motawei and A.M.M. Abd El-Aal, 2010. Nitrogen fertilization influence on combining ability for grain yield and resistance to late wilt disease in maize. J. Agric. Res. Kafr El-Sheikh Univ., 36: 278-291.

Motawei, A.A. and H.E. Mosa, 2009. Genetic analysis for some quantitative traits in yellow maize via half diallel design. Egypt. J. Plant Breed., 13: 223-233.

Motawei, A.A., 2011. Combining ability of some prolific and non-prolific maize inbred lines for grain yield and other related traits. J. Agric. Res. Kafr El-Sheikh Univ., 37: 26-39.

Mousa, S.T.M., 2014. Diallel analysis for physiological traits and grain yield of seven white maize inbred lines. Alex. J. Agric. Res., 59: 9-17.

Nigussie, M. and H. Zelleke, 2001. Heterosis and combining ability in a diallel among eight elite maize populations. Afr. Crop Sci. J., 9: 471-479.

Ojo, G.O.S., D.K. Adedzwa and L.L. Bello, 2007. Combining ability estimates and heterosis for grain yield and yield components in maize (*Zea mays* L.). J. Sustainable Dev. Agric. Environ., 3: 49-57.

Rezaei, A.H. and V. Roohi, 2004. Estimate of genetic parameters in corn (*Zea mays* L.) based on diallel crossing system. New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress Brisbane, September 26-October 1, 2004, Australia.

Rovaris, S.R.S., M.E.A.G. Zagatto and E. Sawazaki, 2014. Combining ability of white corn genotypes with two commercial hybrids. Maydica, 59: 96-103.

Saeed, M.T., M. Saleem and M. Afzal, 2000. Genetic analysis of yield and its components in maize diallel crosses (*Zea mays* L.). Int. J. Agric. Biol., 2: 376-378.

Siddiqui, M.H., F.C. Oad and G.H. Jamro, 2006. Emergence and nitrogen use efficiency of maize under different tillage operations and fertility levels. Asian J. Plant Sci., 5: 508-510.

Socolow, R.H., 1999. Nitrogen management and the future of food: Lessons from the management of energy and carbon. Proc. Natl. Acad. Sci. USA., 96: 6001-6008.

Sprague, G.F. and L.A. Tatum, 1942. General vs. Specific combining ability in single crosses of corn. J. Am. Soc. Agron., 34: 923-932.

Vacaro, E., J.F.B. Neto, D.G. Pegoraro, C.N. Nuss and L.D.H. Conceicao, 2002. Combining ability of twelve maize populations. Pesq. Agropec. Bras. Brasilia, 37: 67-72.

Vidal-Martinez, V.A., M. Clegg, B. Johnson and R. Valdivia-Bernal, 2001. Phenotypic and genotypic relationships between pollen and grain yield components in maize. Agrociencia, 35: 503-511.

Worku, M., M. Banziger, D. Friesen, G.S. Erley, W.J. Horst and B.S. Vivek, 2008. Relative importance of general combining ability and specific combining ability among tropical maize (*Zea mays* L.) inbreds under contrasting nitrogen environments. Maydica, 53: 279-288.

Zaidi, P.H., G. Srinivasan and C. Sanchez, 2003. Relationship between line per se and cross performance under low nitrogen fertility in tropical maize (*Zea mays* L.). Maydica, 48: 221-231.

Zare, M., R. Choukan, E.M. Heravan, M.R. Bihamta and K. Ordookhani, 2011. Gene action of some agronomic traits in corn (*Zea mays* L.) using diallel cross analysis. Afr. J. Agric. Res., 6: 693-703.