Journal of Advances in Biology & Biotechnology
12(1): 1-20, 2017; Article no.JABB.31550
ISSN: 2394-1081

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Elevated Plant Density Effects on Performance and Genetic Parameters Controlling Maize (*Zea mays* L.) Agronomic Traits

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Authors' contributions

This work was carried out in collaboration between both authors. Author AMMAN designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author MMMA managed the experimental process and performed data analysis. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2017/31550
Editor(s):
(1) Ali Movahedi, Forest Genetics and Biotechnology in the College of Forest Resources and Environment, Nanjing Forestry University, Nanjing, Jiangsu, China.
Reviewers:
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(3) Valentin Kosev, Institute of Forage Crops, Pleven, Bulgaria.
Complete Peer review History: http://www.sciencedomain.org/review-history/18063

Original Research Article

Received 13th January 2017
Accepted 28th February 2017
Published 6th March 2017

ABSTRACT

Studying mode of gene action for maize traits under high plant density is a prerequisite for conducting an appropriate breeding program for developing high density tolerant varieties. The objective of this study was to assess maize diallel crosses for mean performance, combining ability and genetic parameters controlling studied traits under elevated plant densities. Experiments were carried out in 2013 and 2014 seasons, using a split-plot design with 3 replicates; main plots were assigned to plant densities, *i.e.* low- (LD), medium- (MD) and high- (HD) density (20,000, 30,000 and 40,000 plants/fed) (fed=feddan=4200 m^2), respectively and sub-plots to 17 genotypes (15 crosses and two checks). Combined analysis across seasons indicated that elevating plant density from 20,000 to 40,000 plants/fed caused a significant decrease in grain yield/plant (GYPP) by 40.18%, leaf angle (LANG) by 25.51% and all yield components, but caused a significant increase in grain yield/fed (GYPF) by 30.0%, plant height (11.34%), ear height (19.41%), days to anthesis (4.35%) and days to silking (3.79%). Significant increase in GYPF due to elevating density to 40,000 plants/fed varied among crosses from 12.22 to 51.90%. The best general combiners for GYPP and

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GYPF were IL92 and IL172 under MD, IL92 for GYPP and IL24 and CML104 for GYPF under HD. Both additive (δ^2_A) and dominance (δ^2_D) variances played important role in controlling the inheritance of most studied traits under all environments. The δ^2_A component was higher than δ^2_D for most studied traits under all plant densities. Estimates of broad- and narrow-sense heritability and genetic advance from selection were the highest in magnitude under high density for 5 traits (barren stalks, ear height, leaf angle, kernels/row and GYPF), under medium density for 3 traits (GYPP, 100-kernel weight and number of kernels/plant and under low density for 6 traits (days to anthesis, days to silking, anthesis-silking interval, plant height, ears/plant and rows/ear).

Keywords: High density; combining ability; gene action; heritability; genetic advance.

1. INTRODUCTION

Maize (*Zea mays* L.) grain yield per unit area is the product of grain yield per plant and number of plants per unit area [1]. Maximum yield per unit area may be obtained by growing maize hybrids that can withstand high plant density up to 100,000 plants ha^{-1} (*ca*. 40,000 plants fed^{-1}) [2]. Average maize grain yield per unit area in the USA increased dramatically during the second half of the 20th century, due to improvement in crop management practices and greater tolerance of modern hybrids to high plant densities [3].

Hybrid varieties of maize currently released in Egypt by the National Maize Breeding Program (NMBP) are bred and grown at low plant density (24,000 plants fed^{-1} or ca. 57,000 plants ha^{-1}), *i.e.* almost half of the density used in developed countries. Growing hybrid varieties released by NMBP at high plant densities causes a drastic reduction in grain yield/plant and consequent reduction in grain yield per unit area. The reason is probably attributed to the sensitivity of these varieties to high plant densities, because of their tallness, one-eared, decumbent leaf and large-size type plants. On the contrary, modern maize hybrids in developed countries are characterized with high yielding ability from unit area under high plant densities, due to their morphological and phenological adaptability traits, such as early silking, short anthesis-silking interval (ASI), less barren stalks and prolificacy [4]. Radenovic *et al*. [5] pointed out that maize genotypes with erect leaves are very desirable for increasing the population density due to better light interception.

To increase maize grain yield per unit area in Egypt, breeding programs should be directed towards the development of inbreds and hybrids that characterize with adaptive traits to high plant density tolerance. Studying mode of gene action for such traits is a prerequisite for conducting an appropriate breeding program for developing high density tolerant varieties. Since the final evaluation of inbred lines can be best determined by hybrid performance, it plays an important role in selecting superior parents for hybrid combinations and in studying the nature of genetic variation [6]. Sprague and Tatum [7] reported that general combining ability (GCA) is associated with additive effects of the genes, while specific combining ability (SCA) is related to dominance and epistatic effects (non-additive effects) of the genes. In general, diallel analysis has been used primarily to estimate GCA and SCA effects and type of gene action from crosses of fixed lines [6]. Investigators reported more proportional and significant GCA effects for yield, days to silk and plant height in different groups of broad based CIMMYT maize populations and pools across locations [8,9]. On the other hand, Singh and Asnani [10] concluded that both GCA (additive) and SCA (non-additive) effects play an important role in the inheritance of yield and its components. Dass et al*.* [11] reported that additive was found to be more sensitive to environmental change than dominance. The demonstration that prolificacy may be rapidly transferred from a prolific to a non-prolific inbred by backcrossing indicates that relatively few genes affect ear number [12]. Hassan *et al*. [13] reported that both dominance gene action and epistatic interactions play major roles in governing the inheritance of ASI. Anthesis-to-silking interval showed evidence for epistatic interactions and locus by density interaction [14]. Mason and Zuber [15] reported that additive and non-additive effects appeared to be equally important in the expression of leaf angle. They also found that crosses of upright-leafed parents tend to produce upright leaf progeny, and *vice versa*. The objective of the present study was to assess 15 F_1 diallel crosses for mean performance, combining ability, genetic components, heritability and genetic advance from selection of some important agronomic and yield traits under different plant densities.

2. MATERIALS AND METHODS

This study was carried out at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 22.50 meters above sea level), in 2012, 2013 and 2014 seasons.

2.1 Plant Material

Six maize (*Zea mays* L.) inbred lines (Table 1) showing clear differences in prolificacy, leaf angle and grain yield under high plant density were chosen as parents for diallel crosses in this study. These inbreds were provided by Maize Research Department, Agricultural Research Center, Egypt.

2.2 Producing F_1 Diallel Crosses

In 2012 season, all possible diallel crosses (except reciprocals) were made among the six parents, so seeds of 15 direct F_1 crosses were obtained for comparative evaluation trials.

2.3 Evaluation of F_1`s

One field evaluation experiment was carried out in 2013 and 2014 seasons at the Agricultural Experiment and Research Station, Faculty of Agriculture, Cairo University. Each experiment included 15 F_1 crosses, their 6 parents and 2 check cultivars, *i.e.* SC 130 (white), obtained from the Agricultural Research Center (ARC) and SC 2055 (yellow) obtained from Hi-Tech Company, Egypt.

Evaluation in each season was carried out under three plant densities, *i.e.* high-density (40,000 plants/fed) (HD), medium- density (30,000 plant/fed) (MD) and low-density (20,000 plant/fed) (LD). A split- plot design in randomized complete blocks (RCB) arrangement with three replications was used. Main plots were devoted to plant density (HD, MD and LD). Sub-plots were devoted to 17 maize genotypes (15 F_1 diallel crosses and 2 check cultivars). Each sub-plot consisted of one ridge of 4 m long and 0.7 m width, *i.e.* the experimental plot area was 2.8 m^2. Seeds were sown in hills at 15, 20 and 30 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill to achieve the 3 plant densities, *i.e.* 40,000, 30,000 and 20,000 plant/fed, respectively. Sowing date was on May 5 and May 8 in 2013 and 2014 seasons, respectively. Nitrogen fertilization at the rate of 120 kg N/fed was added in two equal doses of Urea before the first and second irrigation. Fertilization with calcium superphosphate was performed with soil preparation and before sowing. Weed control was performed chemically with Stomp herbicide before the first irrigation and just after sowing and manually by hoeing twice, the first before the second irrigation and the second before the third irrigation. Irrigation was applied by flooding after three weeks for the second irrigation and every 12 days for subsequent irrigations. Pest control was performed when required by spraying plants with Lannate (Methomyl) 90% (manufactured by DuPont, USA) against corn borers.

The analysis of the experimental soil, as an average of the two growing seasons 2013 and 2014, indicated that the soil is clay loam (4.00% coarse sand, 30.90% fine sand, 31.20% silt, and 33.90% clay), the pH (paste extract) is 7.73, the EC is 1.91 dSm^{-1}, soil bulk density is 1.2 g cm-3, calcium carbonate is 3.47%, organic matter is 2.09%, the available nutrients in mg kg^{-1}were Nitrogen (34.20), Phosphorous (8.86),

Table 1. Designation, origin and most important traits of 6 inbred lines used for making the diallel of this study

Entry designation	Origin*	Institution (country)	Prolificacy*	Productivity* under high density	Leaf* angle
IL-171 (Y)	Rg-37 G.S. [(PI221866×307A)(SC.14)]	ARC-Egypt	Prolific	High	Erect
IL-92(W)	Rg-49 G.S. (Beida × 307) (SC.14)	ARC-Egypt	Prolific	High	Erect
IL-24(W)	G 336 Loc. Bred (H-309 1969, Mexico)	Mexico	Prolific	High	Wide
Sd-7(W)	A.E.D.	ARC-Egypt	Non-Prolific	Low	Erect
CML-104(Y)	CIMMYT population	CIMMYT-Mexico	Unknown	Low	Erect
IL-17(W)	G 268 Jellicarse (*via* recurrent selection)	ARC-Egypt	Non-Prolific	Low	Wide

**Source of information: Maize Research Department, Agricultural Research Center, Egypt. ARC = Agricultural Research Center, A.E.D. = American Early Dent; an old open-pollinated variety, W = White grains and Y = Yellow grains*

Potassium (242), hot water extractable B (0.49), DTPA - extractable Zn (0.52), DTPA - extractable Mn (0.75) and DTPA - extractable Fe (3.17). Meteorological variables in the 2013 and 2014 growing seasons of maize were obtained from Agro-meteorological Station at Giza, Egypt. For May, June, July and August, mean temperature was 27.87, 29.49, 28.47 and 30.33℃, maximum temperature was 35.7, 35.97, 34.93 and 37.07℃ and relative humidity was 47.0, 53.0, 60.33 and 60.67%, respectively, in 2013 season. In 2014 season, mean temperature was 26.1, 28.5, 29.1 and 29.9℃, maximum temperature was 38.8, 35.2, 35.6 and 36.4℃ and relative humidity was 32.8, 35.2, 35.6 and 36.4%, respectively. Precipitation was nil in all months of maize growing season for both seasons.

2.4 Data Recorded

1- Days to 50% anthesis (DTA) (as number of days from planting to anthesis of 50% of plants/plot). 2- Days to 50% silking (DTS) (as number of days from planting to silking of 50% of plants/plot). 3- Anthesis-silking interval (ASI) (as number of days between 50% silking and 50% anthesis of plants/plot). 4- Plant height (PH) (cm) (measured from ground surface to the point of flag leaf insertion for five plants per plot). 5- Ear height (EH) (cm) measured from ground surface to the base of the top most ear relative to the plant height for five plants per plot. 6- Barren stalks (BS) (%) measured as percentage of plants bearing no ears relative to the total number of plants in the plot (an ear was considered fertile if it had one or more grains on the rachis). 7- Leaf angle (LANG) (^{o}) measured as the angle between stem and blade of the leaf just above ear leaf, according to Zadoks *et al*. [16]. 8- Ears per plant (EPP) calculated by dividing number of ears per plot on number of plants per plot. 9- Rows per ear (RPE) using 10 random ears/plot at harvest. 10- Kernels per row (KPR) using the same 10 random ears/plot. 11- Kernels per plant (KPP) calculated as: number of ears per plant × number of rows per ear × number of kernels per row. 12- 100-kernel weight (100-KW) (g) adjusted at 15.5% grain moisture, using shelled grains of each plot. 13- Grain yield/plant (GYPP) (g) estimated by dividing the grain yield per plot (adjusted at 15.5% grain moisture) on number of plants/plot at harvest. 14- Grain yield per feddan (GYPF) in ardab (ard), by adjusting grain yield/plot to grain yield per feddan (one ard = 140 kg and one fed =4200 m^2).

2.5 Biometrical and Genetic Analyses

Analysis of variance of the split-plot design in RCB arrangement was performed on the basis of individual plot observation using the MIXED procedure of SAS ® [17]. Combined analysis of variance across the two seasons was also performed if the homogeneity test was non-significant. Moreover, combined analysis for each environment (LD, MD and HD) separately across seasons was performed as randomized complete block design for the purpose of determining genetic parameters using GENSTAT 10th addition windows software. Least significant difference (LSD) values were calculated to test the significance of differences between means according to Steel *et al.* [18]. Diallel crosses were analyzed to obtain general (GCA) and specific (SCA) combining ability variances and effects and genetic parameters for studied traits according to Griffing [19] Model I (fixed effect) Method 4. Although Griffing's analysis was based on Model I (fixed effect) since parents of the diallels in this study were selected in purpose for the validity of diallel analysis, Model 2 (that assumes random model) of Method 4 was used to estimate genetic components (additive and dominance variances and their interactions with years), heritability and genetic advance from selection. The conclusions obtained will not be generalized, but will help us to characterize our genetic material for its proper use in the future breeding programs. Estimates of additive (δ^2_A) and dominance (δ^2_D) variances and their interactions with years were calculated according to Sharma [20]. Average degree of dominance "a" was calculated by the following equation:"a" = $[2\ \delta^2_D/\ \delta^2_A]^{1/2}$. The estimates of the average degree of dominance "a" were used to indicate the type of dominance, as follows: "a" = 0 indicates no dominance, "a" < 1 indicates partial dominance, "a" = 1 indicates complete dominance and "a" > 1 indicates over dominance. Heritability in the broad (h^2_b) and narrow (h^2_n) sense in F_1's were estimated from the following formulae: $h^2_b = 100\ (\delta^2_G/\delta^2_{ph})$ and $h^2_n = 100\ (\delta^2_A/\delta^2_{ph})$. The expected genetic advance from selection was calculated as follows: $GA = 100\ h^2_n\ k\ \delta_{ph}\ /\ x$ Where: h_n^2 = Heritability in the narrow sense, δ_{ph} = Phenotypic standard deviation, k = Selection differential (the k value for 10% selection intensity) equals (1.76), x = Mean of the crosses for the respective trait.

3. RESULTS

3.1 Analysis of Variance

Combined analysis of variance across years (Y) of the split-plot design for the studied 17 genotypes (G) of maize (15 F_1's + 2 checks) under three plant densities (D) is presented in Table 2. Mean squares due to years were significant (P ≤ 0.05 or 0.01) for all studied 14 traits, except for barren stalks (BS), ears/plant (EPP), rows/ear (RPE) and kernels/row (KPR). Mean squares due to plant densities, were significant (P ≤ 0.05 or 0.01) for all studied traits, except anthesis-silking interval (ASI), indicating that plant density had a significant effect on all studied traits except ASI. Mean squares due to genotypes were significant (P ≤ 0.05 or 0.01) for all studied traits.

Mean squares due to the 1st order interaction, *i.e.* D×Y, G×Y and G×D were significant (P ≤ 0.05 or 0.01) for 4 traits for D×Y, 11 traits for G×Y and 7 traits for G×D. Mean squares due to the 2nd order interaction, *i.e.* G×D×Y were significant (P ≤ 0.05 or 0.01) for 7 traits (DTA, DTS, ASI, LANG, KPR and GYPF).

Combined analysis of variance of a randomized complete blocks design for 14 traits of 17 maize genotypes under three environments; representing 3 plant densities, *i.e.* LD = low density, MD = medium plant density, HD = high plant density, across two seasons (data not presented). Mean squares due to genotypes under all environments were highly significant for all studied traits.

3.2 Effects of Elevated Plant Density

The effects of elevating plant density on the means of studied traits across all genotypes and across the two years are presented in Table 3. The non-stressed environment represented LD

Table 2. Analysis of variance for studied traits of 17 maize genotypes (15 F_1 crosses and two check hybrids) under 3 plant densities combined across two years

SOV	df	Mean squares				
		DTA	**DTS**	**ASI**	**PH**	**EH**
Years (Y)	1	334.64**	132.69**	45.89**	18038**	4848**
Densities (D)	2	178.39**	146.86**	1.53	17947**	10584**
Y x D	2	0.23	11.29**	8.56**	170.15	51.65
Error a	12	0.7	0.32	0.64	75.49	84.28
Genotypes (G)	16	29.30**	21.49**	3.45**	8633**	3224**
G x Y	16	9.86**	10.96**	1.40**	187.21**	165.6**
G x D	32	1.63**	1.93**	2.42**	71.6	49.42*
G x D x Y	32	1.28**	1.25**	0.93**	69.74	23.83
Error b	192	0.41	0.4	0.54	59.97	29.93
		LANG	**BS%**	**EPP**	**RPE**	**KPR**
Years (Y)	1	121.73**	0.84	0.001	0.11	0.13
Densities (D)	2	1402**	2.20*	4.53**	47.94**	1044.49**
Y x D	2	19.43	0.71	0.02	0.16	29.24**
Error a	12	9.3	0.58	0.01	0.24	2.46
Genotypes (G)	16	282.2**	0.90**	0.06**	18.60**	225.71**
G x Y	16	31.77**	0.48*	0.02	0.57**	21.55**
G x D	32	4.37	0.28	0.02	0.29*	5.77**
G x D x Y	32	4.55*	0.26	0.01	0.25	4.63**
Error b	192	3.08	0.26	0.01	0.2	2.37
		100-KW	**KPP**	**GYPP**	**GYPF(ard)**	
Years (Y)	1	270.68**	1311.0	84036**	2034**	
Densities (D)	2	775.73**	4490645**	139677**	1621**	
Y x D	2	7.31	25974**	480	47.14	
Error a	12	2.61	4217.7	652	25.94	
Genotypes (G)	16	133.96**	89017**	7379**	288.6**	
G x Y	16	11.99**	7291.19	510	38.84**	
G x D	32	2.51	8871.08	551	26.05**	
G x D x Y	32	2.8	9038.18	635*	20.75**	
Error b	192	2.25	7916.62	420	9.37	

** and** indicate significance at 0.05 and 0.01 probability levels, respectively. DTA= Days to 50% anthesis, DTS = days to 50% silking, ASI = anthesis-silking interval, PH = plant height, EH = ear height, BS = barren stalks, LANG = leaf angle, EPP = ears per plant, RPE = rows per ear, KPR = kernels per row, KPP = kernels per plant, 100-KW = 100-kernel weight, GYPP = grain yield per plant, GYPF = grain yield per feddan. fed=4200m^2, ard=140kg*

(20,000 plants/fed), while the stressed environments represented MD and HD (30,000 and 40,000 plants/fed, respectively). Mean grain yield/plant was significantly (P ≤ 0.01) reduced due to elevating plant density from 20,000 plants/fed (LD) to 30,000 plants/fed (MD) and 40,000 plants/fed (HD) by 22.05 and 40.18%, respectively.

This reduction was associated with reductions in all yield components, namely EPP (20.21 and 34.69%), RPE (4.69 and 8.90%), KPR (8.48 and 13.83%), KPP (30.39 and 48.71%) and 100-KW (9.19 and 16.75%) at plant density of 30,000 and 40,000 plants/fed, respectively as compared with 20,000 plants/fed.

It is observed that the reduction in number of kernels/plant was about 2 and 3 fold greater than reduction in 100-kernel weight under high plant density (30,000 and 40,000 plants/fed, respectively).

Elevation of plant density from 20,000 plants/fed to 30,000 and 40,000 plants/fed also resulted in significant reductions of LANG (14.12 and 25.51%, respectively).

On the contrary, higher plant densities (30,000 and 40,000 plants/fed) caused a significant increase in grain yield/fed (GYPF) compared with the low-density by 10.79% (an average of 2.82 ard/fed) and 30.00% (an average of 7.83 ard/fed), respectively (Table 3). Moreover, higher plant density (30,000 and 40,000 plants/fed) caused a significant increase in plant height (PH) by 11.93 and 26.49 cm, ear height (EP) by 8.58 and 20.29 cm, days to anthesis (DTA) by 1.42 and 2.56 day, days to silking (DTS) by 1.3 and 2.4 day and barren stalks (BS) by 0.28 and 0.21% as compared with low plant density (20,000 plant/fed), respectively.

3.3 Effects of Genotype

Variation among genotypes (crosses and checks) expressed by range (minimum and maximum values) for studied 15 traits was presented in Table 3. Ranges became wider as plant density increased for GYPF, 100GW, KPR,

Table 3. Means, change (%), maximum (Max) and minimum (Min) values for studied traits in low (LD), medium (MD) and high (HD) density combined across all studied genotypes and across 2013 and 2014 seasons

Density	Mean	Ch%	Max	Min	Mean	Ch%	Max	Min
	DTA (day)				DTS (day)			
LD	60.71	----	62.33	58.67	63.21	----	65.00	61.17
MD	62.13	-2.35**	64.50	59.92	64.51	-2.06**	66.50	62.33
HD	63.35	-4.35**	65.83	60.75	65.61	-3.79**	67.33	63.58
	ASI (day)				PH (cm)			
LD	2.50	----	3.17	1.50	233.57	----	286.00	197.73
MD	2.38	5.09	3.58	1.67	245.50	-5.11**	296.17	210.67
HD	2.26	9.78	4.25	1.08	260.06	-11.34**	299.33	224.33
	EH (cm)				BS%			
LD	104.53	-----	127.33	72.33	0.04	----	0.33	0.0
MD	113.12	-8.22**	137.33	82.00	0.32	-725*	1.50	0.0
HD	124.82	-19.41**	147.17	92.50	0.25	-525	0.83	0.0
	LANG (°)				EPP			
LD	29.02	----	38.67	23.67	1.21	----	1.39	1.08
MD	24.92	14.12**	34.83	19.33	0.96	20.21**	1.07	0.88
HD	21.62	25.51**	30.33	16.50	0.79	34.69**	0.91	0.67
	RPE				KPR			
LD	15.39	----	17.26	13.60	45.89	----	51.46	40.43
MD	14.67	4.69**	16.20	12.64	42.00	8.48**	47.72	34.82
HD	14.02	8.90**	16.31	12.38	39.55	13.83**	45.11	32.56
	KPP				100-KW (g)			
LD	852.84	----	1102.65	691.68	32.88	----	37.20	28.22
MD	593.67	30.39**	723.85	494.08	29.86	9.19**	35.07	24.62
HD	437.43	48.71**	558.94	351.93	27.38	16.75**	32.02	22.77
	GYPP (g)				GYPF (ard)			
LD	181.59	----	224.16	140.49	26.09	----	32.84	18.52
MD	141.55	22.05**	179.10	95.76	28.91	-10.79**	35.84	19.79
HD	108.62	40.18**	145.09	78.40	33.92	-30.00**	42.59	23.87

Ch% = 100(LD - MD or HD)/LD, LD = 20,000 plants/fed, MD = 30.000 plants/fed and HD= 40,000 plants/fed.
** and** indicate significance at 0.05 and 0.01 probability levels, respectively. fed=4200m^2, ard=140kg*

BS, ASI and DTA traits, but became narrower for GYPP, KPP, EPP, PH, DTS and LANG traits. The genotypes under high density ranged from 23.87 to 42.59 ard/fed for GYPF, from 22.77 to 32.02 g for 100GW, 1.08 to 4.25 day for ASI and from 60.75 to 65.83 day for DTA. Under low plant density, genotypes ranged from 140.49 to 224.16 g for GYPP, 691.68 to 1102.65 for KPP, 23.67° to 38.67° for LANG, 1.08 to 1.39 for EPP, 197.73 to 286.00 cm for PH and 61.17 to 65.00 day for DTS.

3.4 Genotype x Plant Density Interaction

Mean grain yield/plant across years under 3 plant densities (LD, MD and HD) for all F_1 crosses and the check cultivars (SC130 and SC 2055) is presented in Table 4. The effect of the first order interaction (G×D) was clearly shown by the F_1 crosses, where the rank of crosses was changed from one environment (plant density) to another, especially when comparing HD with LD environments. The highest GYPP of the F_1 crosses was generally obtained at LD, where competition between plants is at minimum. The highest GYPP in this experiment (224.2 g) was obtained under low-density environment from the cross IL92 × Sd7 followed by the crosses IL172 × Sd7 (201.8 g) and Sd7 × IL24 (190.7g). Under the most severe stress in this experiment (high density), the highest GYPP was obtained by the crosses Sd7 x IL24, IL92 x Sd7 and IL92 x IL17 (127.1, 127.0 and 120.6 g), respectively.

Mean grain yield/fed across years under three density levels for each hybrid and check is presented in Table 4. The rank of F_1 crosses for GYPF varied from one plant density level to another, indicating that the GYPF of a cross differs from one density to another. Comparing to the non-stressed environment (LD), all F_1 crosses showed a significant increase in their GYPF due to increase in plant density with different percentages, except for IL172 x IL24, which showed a decrease in GYPF by increasing plant density, however this decrease was not significant. The increase in GYPF of these crosses under MD and HD over that under LD could be attributed to the elevation of plant density. Significant increase in GYPF due to elevating density to 40,000 plants/fed varied among crosses from 12,22 to 51.90%. This indicates that the magnitude of increase in GYPF due to the increase in plant density would depend on how much the cross tolerated the elevated density stress.

Table 4. Means of grain yield per plant (GYPP), grain yield per feddan (GYPF) and change (Ch%) from low density (LD) to medium (MD) and high density (HD) combined across two seasons

Genotype	GYPP (g)					GYPF (ard)				
	LD	MD	Ch%	HD	Ch%	LD	MD	Ch%	HD	Ch%
					F_1 crosses					
IL172 × IL92	175.7	137.5	21.74**	109.3	37.79**	25.08	27.96	-11.48	38.01	-51.56**
IL172 × IL24	142.7	106.2	25.58**	87.1	38.96**	26.58	24.96	6.09	23.87	10.20
IL172 × Sd7	201.8	165.7	17.89**	111.3	44.85**	26.78	31.37	-17.14**	36.38	-35.85**
IL172 × CML104	140.5	95.8	31.81**	78.4	44.20**	18.52	19.79	-6.86	25.14	-35.75**
IL172 × IL 17	180.9	136.7	24.43**	113.8	37.09**	25.58	26.70	-4.38	34.06	-33.15**
IL92 × IL24	185.9	142.8	23.18**	97.1	47.77**	25.28	33.25	-31.53**	33.76	-33.54**
IL92 × Sd7	224.2	165.2	26.32**	127.0	43.35**	32.84	35.84	-9.14	42.59	-29.69**
IL92 × CML104	157.6	130.3	17.32*	101.5	35.60**	23.32	26.02	-11.58	32.53	-39.49**
IL92 × IL17	188.1	179.1	4.78	120.6	35.89**	29.57	33.55	-13.46**	37.30	-26.14**
IL24 × Sd7	190.6	137.8	27.7**	106.4	44.18**	24.30	28.19	-16.01*	35.30	-45.27**
IL24 × CML104	179.5	118.1	34.21**	91.5	49.03**	20.50	23.40	-14.15	31.14	-51.90**
IL24 × IL17	167.5	131.1	21.73**	102.7	38.69**	27.57	27.84	-0.98	30.94	-12.22*
Sd7 × CML104	189.7	143.2	24.51**	101.5	46.49**	25.85	30.83	-19.26**	30.92	-19.61**
Sd7 × IL24	190.8	149.2	21.80**	127.1	33.39**	30.05	31.24	-3.96	37.84	-25.92**
CML104 × IL17	166.1	126.5	23.84**	104.8	36.91**	23.80	26.83	-12.73	32.88	-38.15**
					Checks					
SC 130	183.4	174.5	4.85	121.7	33.64**	28.74	31.51	-9.64	35.55	-23.70**
SC 2055	222.0	166.6	24.95**	145.1	34.64**	29.18	32.13	-10.11	38.42	-31.67**
LSD 0.05	D=7.79, G=13.47, D×G=21.06					D=1.55, G=2.01, D×G=3.15				

Ch% = 100(LD - MD or HD)/LD, LD = 20,000 plants/fed, MD = 30.000 plants/fed and HD= 40,000 plants/fed.
** and** indicate significance at 0.05 and 0.01 probability levels, respectively. fed=4200m^2, ard=140kg*

The best GYPF in this experiment was obtained under HD (high density) and the best cross in this environment was IL92× Sd7 (42.59 ard), with a significant superiority over SC 2055 (the best check under this environment) by 10.85%. This F_1 cross showed a significant superiority over SC2055 by 11.55 and 12.54% under MD and LD, respectively.

Table 5. Mean squares due to general (GCA) and specific (SCA) combining ability and their interactions with years (Y) for studied characters under three plant densities across 2013 and 2014 years

SOV	df	Mean squares					
		LD	MD	HD	LD	MD	HD
		DTA			**DTS**		
GCA	5	2201**	10751**	4443**	2973**	2802141**	3103**
SCA	9	2436**	24915**	2007**	1518**	2178049**	2484**
GCA/SCA		0.90	0.43	2.21	1.96	1.29	1.25
GCA x Y	5	3791**	14026**	2495**	1902**	1155126**	3549**
SCA x Y	9	1472**	38567**	2707**	1109**	2959430**	1412**
GCA x Y/SCA x Y		2.58	0.36	0.92	1.72	0.39	2.51
		ASI			**LANG**		
GCA	5	2.0	2.92	7.27	136.2**	5563**	161**
SCA	9	3.8	7.73	5.52	304.7**	4202**	222**
GCA/SCA		0.53	0.38	1.32	0.45	1.32	0.73
GCA x Y	5	4.8	1.07	4.15	397.0**	3379**	301**
SCA x Y	9	3.7	2.58	2.73	388.1**	5355**	257**
GCA x Y/SCA x Y		1.30	0.41	1.52	1.02	0.63	1.17
		PH			**EH**		
GCA	5	12453**	91.6**	36153**	7464**	2027**	18768**
SCA	9	23406**	108.5**	40813**	3637**	2589**	3016**
GCA/SCA		0.53	0.84	0.89	2.05	0.78	6.22
GCA x Y	5	25187**	106.5**	44577**	2635**	3360**	4608**
SCA x Y	9	18036**	84.5**	23986**	10869**	2039**	7492**
GCA x Y/SCA x Y		1.40	1.26	1.86	0.24	1.65	0.62
		BS%			**EPP**		
GCA	5	0.01	0.75**	0.14	0.89**	0.39	0.02
SCA	9	0.03	0.20**	0.17	0.56**	0.42	0.02
GCA/SCA		0.33	3.75	0.82	1.59	0.93	1.00
GCA x Y	5	0.03	0.21	0.21	0.87**	0.12	0.02
SCA x Y	9	0.02	0.09	0.2	0.75**	0.24	0.01
GCA x Y/SCA x Y		1.50	2.33	1.05	1.16	0.5	2.0
		RPE			**KPR**		
GCA	5	31.6**	131.8**	111.7**	878**	826**	339**
SCA	9	54.8**	67.5**	72.9**	477**	478**	394**
GCA/SCA		0.58	1.95	1.53	1.84	1.73	0.86
GCA x Y	5	67.6**	43.6**	12.2**	639**	695**	958**
SCA x Y	9	42.6**	72.5**	94.6**	374**	1236**	581**
GCA x Y/SCA x Y		1.59	0.60	0.13	1.71	0.56	1.65
		KPP			**100-KW**		
GCA	5	287276**	142606**	1749	62**	421**	249**
SCA	9	151711**	70360**	3176	496**	308**	361**
GCA/SCA		1.89	2.03	0.55	0.13	1.37	0.69
GCA x Y	5	93776**	187279**	4752	233**	767**	419**
SCA x Y	9	360142**	144495**	1256	683**	601**	450**
GCA x Y/SCA x Y		0.26	1.30	3.78	0.34	1.28	0.93
		GYPP			**GYPF**		
GCA	5	2027**	4556**	1789**	91.6**	20.8**	391.2**
SCA	9	2589**	4847**	834**	108.5**	95.9**	360.8**
GCA/SCA		0.78	0.94	2.15	0.84	0.22	1.08
GCA x Y	5	3360**	1366**	761**	106.5**	98.3**	419.5**
SCA x Y	9	2039**	977*	1247**	84.5**	132.0**	139.8**
GCA x Y/SCA x Y		1.65	1.40	0.61	1.26	0.74	3.00

** and** indicate significance at 0.05 and 0.01 probability levels, respectively*

3.5 Combining Ability Variances

Estimates of variances due to general (GCA) and specific (SCA) combining ability of the diallel crosses of maize for combined data across two seasons under three plant densities are presented in Table 5. Means squares due to GCA and SCA were significant (P≤ 0.01 or 0.05) for all studied traits under all environments, except for ASI under all densities, BS under LD and HD and EPP under MD and HD.

The magnitude of GCA mean squares was higher than that of SCA mean squares (the ratio of GCA/SCA mean squares was higher than unity) for DTS and BS under all densities, KPR and KPP under LD and MD, RPE under MD and HD, EH under LD and HD, EPP under LD, LANG and 100KW under MD and GYPP, GYPF, DTI and DTS under HD conditions.

On the contrary, the magnitude of SCA mean squares was higher than that of GCA mean squares (the GCA/SCA ratio was less than unity) for the rest of cases, the most importantly are PH, and DTA under all environments. It is important to note that under HD the GCA was higher than SCA in 6 traits, namely GYPP, GYPF, DTS, ASI, EH and RPE, however under low-D, GCA was higher than SCA in 5 traits, namely EPP, DTS, EH, KPR and KPP traits, suggesting the high efficiency of selection for these traits under the corresponding plant density conditions.

Results in Table 5 indicated that mean squares due to the SCA × year and GCA × year interactions were highly significant for all studied traits, except for ASI and BS under all environments and EPP under MD and HD. indicating that additive and non-additive variances for most studied traits under the three environments were affected by years. Results for ASI and BS under all environments and EPP under MD and HD, suggest that additive and non-additive variances were not affected by years.

Mean squares due to GCA × year was higher than those due to SCA × year in all environments for three traits (PH, LANG and BS), in two environments for GYPP under LD and MD,GYPF, KPR, DTS and ASI under LD and HD, EH and KPP under MD and HD and three traits (EPP, RPE and DTA) under LD and 100KW under MD, indicating that GCA variance is more affected by years than SCA variance for these traits under the respective environments. On the contrary, means squares due to SCA × year was higher than those due to GCA × year for the rest of cases, suggesting that SCA is more affected by years than GCA for such cases.

3.6 Combining Ability Effects

3.6.1 GCA effects

The best parental inbreds (Table 6) were those showing negative and significant GCA effects for DTA, DTS, ASI, PH, EH, BS and LANG and those of positive and significant GCA effects for EPP, RPE, KPR, KPP, 100-KW, GYPP and GYPF traits. For GYPP, the best inbred in GCA effects was IL92 under high and medium plant densities and the inbreds IL92 and IL172 under medium density. However under low density, the best inbred for GYPP was CML104. For GYPF, the best inbreds in GCA effects were CML104 and IL24 under high density and IL92 and IL172 under medium plant density, but under low density, the best inbreds were Sd7 and IL172. It is observed that the inbreds L92 was the best general combiner for GYPP, under high as well as medium and low plant densities; IL172 was the best combiner under medium density. However, the inbred Sd7, which is the best commercial inbred in Egypt, showed in the present study the best inbred in GCA effects for grain yield under low plant density (GYPF) and medium plant density (GYPP).

Under high density, the inbred CML104 was also the best general combiner for low DTA, DTS and PH, i.e. the best in producing good hybrid combinations for earliness and short plants. Also the best general combiners under HD were the inbred IL92 for narrow leaf angle, more RPE high 100KW and the inbred IL172 for DTS, EH and 100KW traits. Under medium density, the inbreds CML104 for DTS, PH, LANG and 100KW, IL92 for DTA, DTS, EH and RPE, IL172 for PH and RPE and Sd7 for EH were also the best general combiners. Under low density, the inbreds CML104 for DTS, IL172 for DTS and 100KW, Sd7 for DTS, PH and LANG and IL 17 for DTA, PH, LANG, KPR and EPP.

3.6.2 SCA effects

The best crosses in SCA effects (Table 7) was considered those exhibiting significant negative SCA effects for DTA, DTS, ASI, PH, EH, LANG and BS and the worst ones were those showing significant positive SCA effects for the rest of studied traits.

Table 6. Estimates of general combining ability effects of inbred lines for studied traits under low (LD), medium (MD) and high (HD) plant density across seasons

Inbred	LD	MD	HD	LD	MD	HD	LD	MD	HD
		DTA			**DTS**			**PH**	
IL172	-0.72*	13.33**	1.40**	-2.74**	2.88**	-12.42**	17.69**	-7.92	8.06
IL92	-15.59**	-16.22**	10.94**	-1.10**	-1.35**	10.95**	25.11**	32.64**	30.56**
IL24	4.43**	-35.66**	1.58**	3.46**	-1.58**	9.06**	-20.55**	12.12*	25.22**
Sd7	13.01**	8.29**	10.50**	-9.28**	5.40**	10.24**	-20.15**	13.92*	29.47**
CML 104	2.99**	14.71**	1.81**	-10.43**	-1.61**	-5.28**	19.21**	-24.72**	-65.03**
IL17	-4.13**	15.56**	-26.23**	20.09**	-3.73**	-12.55**	-21.31**	-25.92**	-28.28**
SE (ĝi)	0.22	0.26	0.27	0.23	0.24	0.27	4.85	3.98	4.63
SE (ĝi-ĝj)	0.34	0.41	0.42	0.36	0.37	0.42	7.52	6.16	7.18
		EH			**LANG**			**EPP**	
IL172	-0.53	3.59*	-44.57**	1.4	1.25	-1.07	0.06**	-0.18	0.03
IL92	16.01**	-11.43**	6.43	2.74*	6.07**	-1.90*	-0.16**	0.13	-0.03
IL24	-8.03**	-2.75	-17.78**	-0.77	-16.41**	1.14	0.12**	0.14	-0.01
Sd7	4.01**	-7.53**	24.47**	-2.76*	14.50**	4.68**	-0.32**	0.06	-0.02
CML 104	-29.74**	14.08**	0.35	1.99	-20.41**	-2.32*	0.14**	-0.07	0.00
IL17	18.26**	4.04*	31.10**	-2.60*	14.99**	-0.53	0.15**	-0.08	0.04
SE (ĝi)	0.38	1.34	3.32	0.91	0.65	0.72	0.02	0.15	0.02
SE (ĝi-ĝj)	0.59	2.07	5.15	1.41	1.01	1.12	0.03	0.24	0.02
		RPE			**KPR**			**KPP**	
IL172	0.17	0.65**	2.89**	-1.29	-6.82**	1.45	-37.02	-34.2	7.02
IL92	0.64*	3.51**	0.62*	-1.03	-1.32*	-1.26	-34.81	-41.37*	7.1
IL24	1.20**	1.71**	1.25**	4.84**	1.83*	0.17	60.73	28.85	-13.04
Sd7	-2.16**	-1.59**	-3.37**	-1.09	4.27**	-6.26**	183.94**	-46.71*	3.48
CML 104	0.03	-2.30**	-0.11	-9.51**	-6.06**	0.68	-135.46*	-51.90*	-8.29
IL17	0.13	-1.99**	-1.28**	8.07**	8.10**	5.22**	-37.37	145.33**	3.73
SE (ĝi)	0.20	0.19	0.19	0.89	0.58	0.82	15.68	5.79	10.40
SE (ĝi-ĝj)	0.32	0.29	0.29	1.38	0.89	1.27	24.29	8.97	16.12
		100-KW			**GYPF(ard)**			**GYPP**	
IL172	1.86**	-4.20**	-6.46**	-0.66	1.63**	-0.44	3.59	9.63**	3.74*
IL92	-1.49**	0.59*	2.00**	2.72**	0.59	-1.26*	-11.43*	11.64**	11.35**
IL24	-2.02**	-4.47**	1.23**	1.01**	-0.40	3.95**	-2.75	-4.34	-10.06**
Sd7	0.44	-0.73**	0.17	1.16**	-0.45	-6.55**	-7.53*	13.2**	2.06
CML 104	1.65**	2.12**	1.51**	-2.06**	-0.60	4.60**	14.08**	-21.16**	-10.59**
IL17	-0.44	6.69**	1.54**	-2.16**	-0.78*	-0.30	4.04	-8.96*	3.51*
SE (ĝi)	0.27	0.16	0.23	0.44	0.35	0.46	3.00	3.15	1.77
SE (ĝi-ĝj)	0.41	0.25	0.35	0.68	0.55	0.72	4.64	4.89	2.75

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

Under high density, the best crosses in SCA effects for grain yield were IL172 × IL92, IL24 × Sd7, IL24 × CML104, CML104 × IL17, IL172 × IL17 and IL92 × IL17. Superiority of these hybrids in SCA effects for GYPF and/or GYPP was associated with their superiority in GCA effects for some other traits, i.e. KPP for IL172 × IL92, PH for IL24 × Sd7, KPP and DTA for IL24 × CML104,RPE and DTS for CML104 × IL17, RPE for IL172 × IL17 and KPR, PH and DTA for IL92 × IL17.

Under medium density, the best crosses in SCA effects for grain yield were IL172× IL24, IL172 × CML104, IL92 × Sd7, IL92 × IL17, IL172 ×IL92 and IL24 × Sd7. These crosses were also the best in SCA effects for one or more traits under MD, i.e. LANG and EH for IL172× IL24, RPE, EH and DTA for IL172 × CML104, KPR, RPE and EH for IL92 × Sd7, KPP, 100KW, LANG and EH for IL92 × IL17, KPP and DTS for IL172 ×IL92 and 100KW, LANG and DTS for IL24 × Sd7.

Under low plant density, the best crosses in SCA effects for grain yield were IL172× IL17, IL24 × CML104, IL24 × IL17, Sd7 × CML104, IL172 × CML104, IL92 x IL24 and IL92 × Sd7. These crosses were also the best in SCA effects for one or more traits under LD, i.e. KPR, 100KW and EH for IL172× IL17, EPP and DTS for IL24 × CML104, LANG for IL24 × IL17, DTA for Sd7 × CML104, EPP, RPE, EH and PH for IL172 × CML104, KPR, RPE,100KW and DTA for IL92 x IL24 and KPP, EH and DTS for IL92 × Sd7.

Table 7. Estimates of specific combining ability effects of F_1 crosses for studied traits under low (LD), medium (MD) and high (HD) plant density across seasons

Cross	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**
		DTA			**DTS**			**PH**	
IL172 × IL92	-11.67**	5.17**	14.32**	-15.22**	-451.92**	5.25**	22.82**	-4.01	11.7
IL172 × IL24	-4.02**	-15.11**	20.42**	7.22**	724.77**	-26.19**	-64.19**	-0.8	-120**
IL172 × Sd7	-10.11**	101.62**	-16.66**	-7.20**	5.96**	4.04**	76.41**	-0.75	15.45
IL172 × CML104	-5.58**	-46.09**	-8.89**	22.61**	-133.89**	-10.69**	-75.61**	4.2	51.28**
IL172 × IL 17	31.38**	-45.59**	-9.19**	-7.41**	-144.92**	27.58**	40.57**	1.36	41.53**
IL92 × IL24	-17.31**	55.03**	-16.45**	7.57**	-457.47**	12.69**	46.06**	4.51	89.87**
IL92 × Sd7	30.60**	-19.17**	6.21**	-8.18**	993.64**	-18.17**	-8.68	6.92*	6.95
IL92 × CML104	10.46**	-24.68**	13.65**	-6.95**	-245.68**	-4.15**	-2.69	-4.39	-40.55**
IL92 × IL17	-12.08**	-16.35**	-17.73**	22.78**	161.43**	4.38**	-57.51**	-3.03	-67.96**
IL24 × Sd7	8.83**	-7.17**	12.32**	15.26**	-771.63**	11.15**	-5.7	-4.91	-18.72*
IL24 × CML104	17.61**	-4.31**	-9.08**	-14.93**	24.88**	-1.17**	59.36**	-0.49	-64.88**
IL24 × IL17	-5.11**	-28.44**	-7.20**	-15.12**	479.46**	3.52**	-35.53**	1.68	113.70**
Sd7 × CML104	-18.81**	-45.29**	-15.83**	-0.18	311.34**	27.23**	-47.78**	-0.29	68.87**
Sd7 × IL24	-10.52**	-29.99**	13.96**	0.3	-539.31**	-24.25**	-14.26	-0.98	-72.55**
CML104 × IL17	-3.67**	120.37**	20.15**	-0.55	43.34**	-11.23**	66.73**	0.97	-14.72
SE (ŝij)	0.37	0.44	0.46	0.39	0.41	0.46	8.23	3.38	7.86
SE (ŝij-ŝik)	0.58	0.7	0.72	0.62	0.65	0.73	13.02	5.34	12.43
SE (ŝij-ŝkl)	0.47	0.57	0.59	0.51	0.53	0.6	10.63	4.36	10.15
		EH			**LANG**			**EPP**	
IL172 × IL92	-1.01	28.11**	13.85*	-10.99**	28.92**	2.98*	0.1	0.16	0.01
IL172 × IL24	-28.63**	-13.62**	17.22**	-6.32**	18.19**	-10.06**	-0.18	0.16	-0.04
IL172 × Sd7	9.49**	0.31	-13.36*	7.85**	-2.52*	7.23**	-0.19	0.3	0
IL172 × CML104	25.91**	-32.61**	-0.73	3.77*	-15.64**	-2.77*	0.29*	-0.11	-0.03
IL172 × IL 17	-5.76**	17.81**	-16.98**	5.68**	-28.96**	2.61*	-0.02	-0.51	0.06
IL92 × IL24	11.66**	-5.37*	-5.78	7.69**	-10.52**	6.94**	0.14	-0.17	0.05
IL92 × Sd7	-34.39**	-12.32**	9.48	-1.98	-9.12**	-8.60**	0.19	-0.06	0.02
IL92 × CML104	-12.80**	-0.47	-24.73**	0.26	15.06**	-2.1	-0.49**	0.01	-0.06
IL92 × IL17	36.53**	-9.96**	7.18	5.02**	-24.34**	0.78	0.08	0.06	-0.02
IL24 × Sd7	21.49**	-4.52	-34.65**	-2.65	-18.26**	-0.31	-0.21	-0.09	0

Cross	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**
	DTA			**DTS**			**PH**		
IL24 × CML104	0.57	12.78**	24.64**	5.27**	11.21**	4.36**	0.44**	0.06	-0.02
IL24 × IL17	-5.09**	10.73**	-1.44	-3.99*	-0.62	-0.93	-0.19	0.03	0.01
Sd7 × CML104	7.70**	27.71**	14.06*	-2.9	-17.32**	2.32	-0.08	-0.26	0.06
Sd7 × IL24	-4.30**	-11.18**	24.47**	-0.32	47.22**	-0.64	0.29*	0.11	-0.09
CML104 × IL17	-21.39**	-7.41**	-13.24*	-6.40**	6.69**	-1.81	-0.15	0.3	0.05
SE (ŝij)	0.65	2.27	5.64	1.54	1.1	1.22	0.04	0.26	0.03
SE (ŝij-ŝik)	1.02	3.59	8.92	2.44	1.74	1.94	0.06	0.41	0.04
SE (ŝij-ŝkl)	0.84	2.93	7.28	1.99	1.42	1.58	0.05	0.33	0.03
	RPE			**KPR**			**KPP**		
IL172 × IL92	-1.16**	-1.24**	-4.75**	-0.26	-4.14**	-6.79**	-41.62	17.08	2.55
IL172 × IL24	-1.14**	0.83*	0.51	-9.33**	-3.66**	-8.25**	234.94**	192.83**	26.54
IL172 × Sd7	0.06	-2.00**	2.56**	-1.11	-3.50**	14.98**	-225.70**	-24.87	19.87
IL172 × CML104	3.64**	3.67**	0.19	1.99	4.07**	1.31**	52.37	12.91	-18.96
IL172 × IL 17	-1.40**	-1.27**	1.49**	8.70**	7.22**	-1.25	-19.99	-197.95**	-30
IL92 × IL24	2.73**	3.03**	6.57**	13.77**	-11.78**	9.60**	-149.12	-77.12*	10.48
IL92 × Sd7	-1.53**	3.23**	-1.28**	-5.65**	11.15**	-1.5	186.44*	6.89	-27.42
IL92 × CML104	-2.58**	-0.25	1.24**	4.38**	3.36**	-5.82**	62.96	7.73	4.41
IL92 × IL17	2.54**	-4.78**	-1.78**	-12.25**	1.41	4.50**	-58.66	45.43	9.98
IL24 × Sd7	3.90**	-3.49**	-0.89**	-4.37**	5.16**	-6.38**	67.31	-47.12	-7.66
IL24 × CML104	-2.63**	-2.38**	-3.33**	-3.40*	10.94**	3.38*	-52.8	-94.98**	-8.77
IL24 × IL17	-2.86**	2.00**	-2.85**	3.34*	-0.67	1.65	-100.33	26.38	-20.59
Sd7 × CML104	-1.29**	-1.42**	-0.81*	3.98*	-11.61**	-0.54	-134.77	6.65	-1.03
Sd7 × IL24	-1.14**	3.67**	0.43	7.15**	-1.21	-6.57**	106.72	58.44	16.25
CML104 × IL17	2.86**	0.37	2.71**	-6.95**	-6.76**	1.67	72.25	67.69*	24.35
SE (ŝij)	0.35	0.32	0.32	1.52	0.98	1.39	26.61	9.82	17.65
SE (ŝij-ŝik)	0.55	0.5	0.5	2.4	1.54	2.2	42.08	15.53	27.91
SE (ŝij-ŝkl)	0.45	0.41	0.41	1.96	1.26	1.79	34.36	12.68	22.79
	100-KW			**GYPP**			**GYPF(ard)**		
IL172 × IL92	-8.35**	3.94**	2.48*	28.11	-35.43*	26.22**	-4.01	3.89*	-4.14
IL172 × IL24	7.37**	-0.63	3.36**	-13.62	49.22**	-4.57	-0.8	-3.12	-3.48
IL172 × Sd7	-8.81**	5.58**	-1.06	0.31	-8.77	-7.53	-0.75	-1.66	-0.48
IL172 × CML104	3.60*	2.01*	-7.43**	-32.61*	10.6	-7.74	4.2	1.91	2.14

Cross	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**
		DTA			**DTS**			**PH**	
IL172 × IL 17	6.19**	-10.90**	2.65*	17.81	-15.63	-6.38	1.36	-1.01	5.96*
IL92 × IL24	10.12**	-1.80*	-3.01*	-5.37	-16.15	-12.22	4.51	1.21	-2.77
IL92 × Sd7	-2.86*	-9.47**	4.70**	-12.32	38.72*	-4.43	6.92**	-6.16**	1.55
IL92 × CML104	6.12**	-2.51**	9.44**	-0.47	-11.88	-7.29	-4.39	-0.83	-4.65
IL92 × IL17	-5.03**	9.84**	-13.61**	-9.96	24.73	-2.28	-3.03	1.88	10.01**
IL24 × Sd7	-5.03**	7.33**	1.28	-4.52	-22.7	6.4	-4.91*	7.19**	-0.95
IL24 × CML104	-8.15**	-2.89**	-0.98	12.78	-3.12	9.14	-0.49	-2.45	13.75**
IL24 × IL17	-4.31**	-2.02*	-0.66	10.73	-7.24	1.25	1.68	-2.83	-6.55**
Sd7 × CML104	5.99**	-1.56	-8.78**	27.71	-0.49	2.02	-0.29	0.03	-0.98
Sd7 × IL24	10.71**	-1.88*	3.87**	-11.18	-6.75	3.55	-0.98	0.61	0.85
CML104 × IL17	-7.56**	4.95**	7.75**	-7.41	4.89	3.87	0.97	1.35	-10.26**
SE (ŝij)	1.36	0.81	1.16	5.09	5.35	3.01	0.75	0.60	0.79
SE (ŝij-ŝik)	2.15	1.28	1.84	8.04	8.47	4.76	1.18	0.95	1.24
SE (ŝij-ŝkl)	1.75	1.04	1.5	6.57	6.91	3.89	0.96	0.77	1.01

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

3.7 Genetic Components, Heritability and Genetic Advance

Estimates of variance components, heritability and genetic advance from selection for studied traits under 3 plant densities across two years are presented in Table 8. Both additive and dominance variances played important role in controlling the inheritance of most studied traits under all environments. The additive genetic component of variation (δ^2_A) was higher than dominance variance (δ^2_D) for most studied traits under all plant densities, as expressed by lower ratio of (δ^2_A / δ^2_D) than unity. The estimates of dominance were much higher, in magnitude, than additive variance for ASI, PH, LD and RPE under high density, DTA, PH, BS, LANG and KPR under medium density and EH and KPP under low density.

Table 8. Additive (δ^2_A), dominance (δ^2_D), genetic (δ^2_g) and phenotypic (δ^2_{ph}) variance, average degree of dominance "a", heritability in broad (h^2_b) and narrow (h^2_n) sense for studied traits under low (LD), medium (MD) and high plant density across seasons

Parameter	LD	MD	HD	LD	MD	HD
	DTA			DTS		
δ^2_A	91.12	99.7	97.3	763	123	423
δ^2_D	69	730.3	6.3	24	53	64
δ^2_A / δ^2_D	1.32	0.14	15.37	32.34	2.3	6.64
"a"	1.23	3.83	0.36	0.25	0.93	0.55
δ^2_{AY}	96.6	1022.5	8.84	33	75	89
δ^2_{DY}	245.3	6427.8	451.11	185	493	235
δ^2_{AY} / δ^2_{DY}	0.39	0.16	0.02	0.18	0.15	0.38
δ^2_e	0.04	0.06	0.06	0.04	0.05	0.06
δ^2_g	160.12	830.03	103.63	786.20	176.16	486.17
δ^2_{Ph}	502.09	8280.41	563.64	1004.07	744.21	810.54
h^2_b	31.89	10.02	18.39	78.30	23.67	59.98
h^2_n	18.15	1.20	17.26	75.95	16.53	52.13
GA%	11.80	3.11	11.40	66.99	11.30	39.84
	ASI			PH		
δ^2_A	0.3	0.06	0.02	530.58	0.62	351
δ^2_D	0.03	0.05	0.04	447.5	2.00	1402.25
δ^2_A / δ^2_D	10	1.2	0.5	1.19	0.31	0.25
"a"	0.45	1.29	2.00	1.30	2.54	2.83
δ^2_{AY}	0.045	0.065	0.06	298	0.915	857.9
δ^2_{DY}	0.570	0.370	0.36	2987	10.92	3980.5
δ^2_{AY} / δ^2_{DY}	0.08	0.18	0.17	0.10	0.08	0.22
δ^2_e	0.05	0.06	0.09	18.83	3.17	17.17
δ^2_g	0.33	0.11	0.06	978.1	2.62	1753.25
δ^2_{Ph}	1.00	0.61	0.57	4282.0	17.63	6608.88
h^2_b	33.17	18.18	10.53	22.84	14.87	26.53
h^2_n	30.15	9.92	3.51	12.39	3.52	5.31
GA%	0.87	0.22	0.07	22.57	0.40	11.59
	EH			BS%		
δ^2_A	201.2	55.54	590	0.0	0.0	0.01
δ^2_D	602.67	45.83	373	0.0	0.0	0.0
δ^2_A / δ^2_D	0.33	1.21	1.58	0.0	0.67	0.0
"a"	2.45	1.28	1.12	0.00	0.00	0.00
δ^2_{AY}	343.09	55.04	120.17	0.00	0.005	0.0
δ^2_{DY}	1811.38	338.41	1239.83	0.02	0.05	0.01
δ^2_{AY} / δ^2_{DY}	0.19	0.16	0.10	0.00	0.10	0.00
δ^2_e	0.12	1.43	8.83	0.02	0.07	0.04
δ^2_g	803.87	101.37	963.00	0.00	0.00	0.01
δ^2_{Ph}	2958.46	496.25	2331.83	0.04	0.13	0.06
h^2_b	27.17	20.43	41.30	0.00	0.00	16.67
h^2_n	6.80	11.19	25.30	0.00	0.00	16.67
GA%	10.74	7.07	33.99	0.00	0.00	0.11
	LANG			EPP		
δ^2_A	12.88	8.08	12.36	0.03	0.00	0.00
δ^2_D	0.27	58.83	1.33	0.00	0.00	0.00

Parameter	**LD**	**MD**	**HD**	**LD**	**MD**	**HD**
δ^2_A / δ^2_D	47.7	0.14	9.29	8.67	1.33	0.00
"a"	0.20	3.82	0.46	0.00	0.00	0.00
δ^2_{AY}	0.37	82.34	1.84	0.005	0.005	0.00
δ^2_{DY}	64.02	892.16	42.42	0.12	0.13	0.00
$\delta^2_{AY} / \delta^2_{DY}$	0.01	0.09	0.04	0.04	0.04	0.00
δ^2_e	0.66	0.34	0.42	0.00	0.17	0.00
δ^2_g	13.15	66.91	13.69	0.03	0.00	0.00
δ^2_{Ph}	78.20	1041.75	58.37	0.16	0.31	0.00
h^2_b	16.82	6.42	23.46	19.35	0.00	0.00
h^2_n	16.47	0.78	21.18	19.35	0.00	0.00
GA%	4.23	0.71	4.50	0.21	0.00	0.00
		RPE			**KPR**	
δ^2_A	2.38	1.8	1.54	102.04	0.26	198.26
δ^2_D	0.74	0.86	2.45	7.92	16.08	11.17
δ^2_A / δ^2_D	3.22	2.09	0.63	12.88	0.02	17.75
"a"	0.79	0.98	1.78	0.39	11.12	0.34
δ^2_{AY}	1.04	1.21	3.44	11.04	22.54	15.7
δ^2_{DY}	7.07	12.06	15.74	61.7	205.74	96.3
$\delta^2_{AY} / \delta^2_{DY}$	0.15	0.10	0.22	0.18	0.11	0.16
δ^2_e	0.03	0.03	0.03	0.64	0.27	0.54
δ^2_g	3.12	2.66	3.99	109.96	16.34	209.43
δ^2_{Ph}	11.26	15.96	23.20	183.34	244.89	321.98
h^2_b	27.71	16.67	17.20	59.98	6.67	65.04
h^2_n	21.14	11.28	6.64	55.66	0.11	61.58
GA%	2.06	1.28	0.89	20.98	0.05	29.66
		KPP			**100-KW**	
δ^2_A	6593.16	6874.16	188.84	24.92	25.16	17.42
δ^2_D	7927.58	1273.33	104.08	13.42	4.92	0.92
δ^2_A / δ^2_D	0.83	5.4	1.81	1.86	5.11	18.93
"a"	1.55	0.61	1.05	1.04	0.63	0.33
δ^2_{AY}	11098.59	1782.67	145.66	18.75	6.92	1.29
δ^2_{DY}	58253.17	23841.33	569.83	113.32	99.99	74.63
$\delta^2_{AY} / \delta^2_{DY}$	0.19	0.07	0.26	0.17	0.07	0.02
δ^2_e	1770.5	241.17	779.17	0.51	0.18	0.38
δ^2_g	14520.74	8147.49	292.92	38.34	30.08	18.34
δ^2_{Ph}	85643.00	34012.66	1787.59	170.92	137.17	94.64
h^2_b	16.95	23.95	16.39	22.43	21.93	19.38
h^2_n	7.70	20.21	10.56	14.58	18.34	18.41
GA%	65.39	105.77	12.43	5.31	5.87	4.81
		GYPP			**GYPF**	
δ^2_A	127.8	875.20	30.2	3.3	3.49	14.28
δ^2_D	39.33	11.58	14.42	0.66	1.01	8.33
δ^2_A / δ^2_D	3.25	75.58	2.09	5.01	3.46	1.72
"a"	0.78	0.16	0.98	0.63	0.76	1.08
δ^2_{AY}	55.04	16.21	20.25	0.915	1.41	11.66
δ^2_{DY}	275.17	91.17	185.17	12.69	21.1	21.76
$\delta^2_{AY} / \delta^2_{DY}$	0.20	0.18	0.11	0.07	0.07	0.54
δ^2_e	64.67	71.67	22.67	1.40	0.90	1.54
δ^2_g	167.13	886.8	44.62	3.96	4.50	22.61
δ^2_{Ph}	562.01	1065.8	272.71	18.97	27.91	57.57
h^2_b	29.74	83.20	16.36	20.88	16.13	39.28
h^2_n	22.74	82.11	11.07	17.40	12.51	24.81
GA%	15.65	76.07	5.09	2.11	1.80	5.05

Average degree of dominance "a" was greater than unity for PH and EH under the 3 plant densities, DTA under LD and MD, KPP under LD and HD, ASI under MD and HD, LANG and KPR under MD, GYPF and RPE under HD and 100KW under LD, indicating that the degree of dominance in these cases was over dominance. The rest of cases showed partial dominance. The magnitude of variance due to interaction of dominance with years (δ^2_{DY}) was much higher than that due to interaction of additive with years (δ^2_{AY}), as expressed by the ratio $\delta^2_{AY} / \delta^2_{DY}$ of less than unity.

Broad-sense heritability (h^2_b) was generally below average in magnitude for most studied traits under all densities. The lowest estimates of h^2_b were shown by EPP (0,0% under MD and HD), BS (0.0% under LD and MD) and KPR (6.67% under MD). The highest estimate of h^2_b was shown by GYPP under MD (83.20%) followed by DTS under low density (78.30%). Narrow-sense heritability (h^2_n) was generally of small magnitude but reached high estimate (82.11%) for GYPP, under medium plant density.

It is also observed that maximum number (7) of traits (GYPF, 100KW, KPR, EPP, LANG, BS, and EH) showed the highest estimates of broad-sense and narrow-sense heritability under high density environment, 5 traits (DTA, DTS, ASI, PH, and RPE) under low density, but only two traits (GYPP and KPP) under medium density environment.

Expected genetic advance (GA) from selection (based on 10% selection intensity) across years for studied traits in the three densities (Table 8) was generally of small magnitude and ranged from 0.0% for BS under all densities and EPP under MD and HD to 76.07% for GYPP under medium density. High density environment showed higher GA% than other densities for BS, EH, LANG, KPR and GYPF, low density showed higher GA% for DTA, DTS, ASI, PH, EPP, RPE and medium density for GYPP, KPP and 100KW.

4. DISCUSSION

Although high plant density results in interplant competition (especially for light, water and nutrients), which affects vegetative and reproductive growth of maize [21], the use of high-density tolerant hybrids would overcome the negative impacts of such competition and lead to maximizing maize productivity from the same unit area. Developing high density tolerant Egyptian cultivars is important to enable these cultivars to produce a higher grain productivity than present cultivars. Nature of inheritance of such traits should be studied; such information in Egypt is scarce. Results of the present study indicated that the three studied factors, year, plant density and genotype had a significant effect on all studied agronomic and yield traits, except anthesis-silking interval (ASI) for year and plant density. The rank of maize genotypes differ from one density to another, indicating the possibility of selection for improved performance of such traits under a specific plant density as proposed by Kamara et al. [22] , Shakarami and Rafiee [23] and Al-Naggar et al. [24-27].

The obvious reduction in grain yield/plant (GYPP), ears/plant (EPP) and kernels/plant (KPP) due to elevating plant density from 20,000 to 40,000 plants/fed indicated the importance of these traits as measures of tolerance to high-density. This result was previously reported by Al-Naggar et al. [28, 29]. Higher reduction in KPP than 100-kernel/plant (100KW) under high density is consistent with previous investigators on high-density stress in maize [30,31,32]. Considerable evidence indicates that maize plants exposed to high plant density stress have reduced EPP, KPP and kernel weight [33,34]. The reductions in yield components are logic and could be attributed to the increase in competition between plants at higher densities for light, nutrients and water. This result was previously reported by several investigators [29,34,35].

Elongation of plant stalks and raise of ear position exhibited in this study due to elevating the plant densities could be attributed to lower light level and greater competition between plants for light. This conclusion was previously reported by other investigators [36-38], Significant reduction in leaf angle (erectness) is the result of elevation of plant density in this study, which is in consistency with Edmeades et al. [39] and Al-Naggar et al. [27,28,38,40].

Delayed silking under conditions of high-density stress is related to less assimilates being partitioned to growing ears around anthesis, which results in lower ear growth rates, increased ear abortion, and more barren plants [36]. When assimilate supply is limited under stress, it is usually preferentially distributed to the stem and tassel at the expense of ear nutrition, leading to poor pollination and partial or complete failure of seed set. This occurs with practically all kinds of stress, including drought, low soil N and P, excess moisture, low soil pH, iron deficiency and high population density [37,41].

The highest GYPP in this experiment was obtained under low-density environment from the crosses IL92 × Sd7, IL172 × Sd7 and Sd7 × IL24; these crosses could therefore be considered responsive to this good environment. Under the most severe stress in this experiment (high density), the highest GYPP was obtained by the crosses Sd7 x IL24, IL92 x Sd7 and IL92 x IL17; these crosses were considered tolerant to high density stress. It is clear that Sd7 and IL92 inbred parents might be considered as source of tolerance and responsiveness in these crosses. It is worthy to note that the three crosses IL92×

Sd7, Sd7 x IL24 and IL92 x IL17 were considered the highest responsive and the most tolerant ones to high density stress.

The best general combiners for GYPP and GYPF were IL92 and IL172 under MD, IL92 for GYPP and IL24 and CML104 for GYPF under HD and CML104 for GYPP and IL92 and Sd7 for GYPF under LD. This means that these inbreds (L92 and CML104) could be used in the future plant breeding programs for developing suitable hybrids for high plant density and the inbreds L172 and Sd7 for low and/or medium plant densities. Superiority of these inbreds in GCA effects for GYPF and/or GYPP was associated with their superiority in GCA effects for some other traits. It should be noticed that for more ears/plant (EPP), the inbred IL17 was the best general combiner under low plant density. Previous studies proved that positive GCA effects for EPP and kernels/plant and negative GCA effects for DTA, DTS, BS, and LANG traits are a good indicator of high density and/or drought stress tolerance [33,42].

It is observed that the crosses IL92 × IL17, IL172 ×IL92 and IL24 × Sd7 were the best in SCA effects for grain yield under both high and medium plant densities. These crosses could be offered to plant breeding programs for improving tolerance to high plant density tolerance. It is observed that the crosses IL172 × IL17 and IL24 × CML104 were the best in SCA effects for grain yield under both high and low plant densities and the cross IL172 × CML104 was the best under both low and medium density. It is worthy to note that for the studied traits, most of the best crosses in SCA effects for a given trait included at least one of the best parental inbred lines in GCA effects for the same trait. The same conclusion was confirmed previously by Al-Naggar et al. [33,40,43].

Analysis of variance components indicated the presence of both additive and dominance variances for most studied traits with predominance of additive variance, indicating that both selection and heterosis breeding methods might be used for improving these traits under elevated plant density. A similar conclusion was reported by Mason and Zuber [15], Khalil and Khattab [44] and Al-Naggar et al. [27,29,32]. The predominance of dominance variance in ASI, PH, LD and RPE under high density, DTA, PH, BS, LANG and KPR under medium density and EH and KPP under low density suggests that dominance variance plays the major role in the inheritance of these traits and that heterosis breeding would be more efficient than selection for improving studied traits under respective environments. This result is in agreement with that reported by Derera et al. [45], El-Shouny et al. [46], Al-Naggar et al. [38,40,43]. The higher magnitude of (δ^2_{DY}) than that of (δ^2_{AY}) indicates that dominance variance was more affected by years than additive variance for all studied traits under all plant densities. These results are in agreement with those reported by Khalil and Khattab [44], El-Shouny et al. [46], and Al-Naggar et al. [25,31, 32].

Below average estimates of broad-sense heritability for most studied traits in this study under different plant densities indicate that the environment and genotype × environment interaction had considerable effects on the phenotype for such traits. Estimates of broad- and narrow-sense heritability and genetic advance from selection were the highest in magnitude under high density for 5 traits (barren stalks, ear height, leaf angle, kernels/row and GYPF), under medium density for 3 traits (GYPP, 100-kernel weight and number of kernels/plant and under low density for 6 traits (days to anthesis, days to silking, anthesis silking interval, plant height, ears/plant and rows/ear). In the literature, there are two contrasting conclusions, based on results regarding heritability and predicted genetic advance (GA) from selection under stress and non-stress environments. Many researchers found that heritability and GA from selection for grain yield is higher under non-stress than those under stress [33,47,48]. However, other investigators reported that heritability and expected GA for the same trait is higher under stress than non-stress, and that selection should be practiced in the target environment to obtain higher genetic advance [40,43,49,50].

It is therefore expected that to improve BS, EH, LANG, KPR and GYPF in the present germplasm, it is better to practice selection for these traits under high-density stressed environment, but to improve DTA, DTS, ASI, PH, EPP and RPE, it is better to practice selection under low density stress, and to improve GYPP, KPP and 100KW, it is better to practice selection under medium density conditions to obtain higher values of selection gain.

5. CONCLUSION

The genetic material of maize used in this study showed an average increase in grain yield/fed (GYPF) due to increasing plant density from 20,000 to 40,000 plants/fed. The magnitude of increase in GYPF due to the increase in plant density was dependent on genotype. The best cross in GYPF under high density environment was IL92× Sd7 (42.59 ard/fed), with a significant superiority over SC 2055 (the best check) by 10.85%. The best general combiners for grain yield/plant (GYPP) and GYPF were IL92 and IL172 under MD (30,000 plants/fed), IL92 for GYPP and IL24 and CML104 for GYPF under HD (40,000 plants/fed). These inbreds could be used in the future plant breeding programs for developing suitable hybrids for high plant density and the inbreds L172 and Sd7 for low and/or medium plant densities. Both selection and heterosis breeding procedures might be used for improving most studied traits under elevated plant density. The study concluded that to improve BS, EH, LANG, KPR and GYPF in the present germplasm, it is better to practice selection in segregating populations of the studied crosses for these traits under high-density stressed environment, but to improve DTA, DTS, ASI, PH, EPP and RPE, it is better to practice selection under low density stress, and to improve GYPP, KPP and 100KW, it is better to practice selection under medium density conditions to obtain higher values of selection gain.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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