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High Planting Density Tolerance of New Maize Hybrids for Yield Improvement

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Improving maize yield under high planting densities has become a crucial focus in breeding programs aiming to optimize resource use and maximize productivity. This study evaluated the general combining ability (GCA) of nine yellow maize inbred lines and the specific combining ability (SCA) of their hybrids in relation to grain yield under two plant densities and two nitrogen fertilization rates. A half-diallel mating scheme was conducted during the 2023 summer season, generating 36 hybrids. These hybrids, along with two commercial checks (SC168 and SC178), were evaluated at Sakha Agricultural Research Station, Egypt, during the 2024 season using a split-split plot design with three replications. Field trials were performed under nitrogen rates of 286 and 400 kg N/ha, and planting densities of 59,524 and 83,333 plants/ha. Results showed that increasing nitrogen application significantly improved grain yield per hectare and per plant by 8.8% and 7.6%, respectively. Higher plant density also led to an 18.12% increase in grain yield per hectare, though yield per plant declined by 9.28%. Both GCA and SCA effects were statistically significant, revealing that additive and non-additive genetic effects contributed to yield performance, with a stronger role observed for additive effects. Inbred lines P2, P3, P8, and P9 showed desirable GCA effects. The hybrids P2×P8, P2×P9, P3×P7, P3×P8, and P5×P8 surpassed the commercial checks across all tested environments, especially under high-density conditions. These hybrids are recommended for further evaluation in maize improvement programs targeting crowding stress tolerance and yield enhancement

Keywords: Diallel crosses, Inbred lines, Additive and Non-additive genetic effects, High-yielding hybrids, Maize breeding.

1. Introduction

Maize (*Zea mays* L.) ranks among the top three staple cereal crops worldwide (**Ali and Abdelaal, 2020; Maswada *et al*., 2021**), and it is the second most important cereal cultivated in Egypt in terms of harvested area and production, following wheat. Despite its strategic importance, local maize production in Egypt covers only around 50% of domestic consumption. Therefore, increasing grain yield per unit area is essential to bridge this production-consumption gap, either through enhancing the yield potential per plant or by improving crop performance under higher planting densities. As plant density increases, yield per plant tends to decline due to intensified interplant competition for resources such as light, water, and nutrients. However, overall yield per hectare may still improve if hybrids possess tolerance to crowding stress. This has been demonstrated by the notable yield increases in the United States during the latter half of the 20th century, largely attributed to improved agronomic practices and the development of hybrids capable of thriving under high-density planting conditions (**Mansour *et al*., 2024**). In line with this, Egyptian maize breeding programs are actively developing hybrids that perform well under high plant densities. Although high-density planting can negatively affect maize growth due to increased competition, the use of tolerant hybrids can help mitigate these effects and enhance productivity per unit area (**Ali and Abdelaal, 2020**). It is also essential to consider genotype × environment interactions when managing plant density, as different genotypes respond differently to environmental conditions (Hernandez et al., 2014; **Mohamed, 2020**). Studies have shown that better environments often achieve

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higher yields at increased plant densities (Al-Kaisi and Yin, 2003; **Metwally *et al.*, 2018**). This underscores the importance of identifying optimal plant densities for specific environments (Robles et al., 2012; Reeves and Cox, 2013; **Ali and Abdelaal, 2020**). Hybrid performance is strongly influenced by the combining abilities of their parental inbred lines, as described by Sprague and Tatum (1942). General combining ability (GCA) reflects additive genetic effects, whereas specific combining ability (SCA) is associated with non-additive effects such as dominance and epistasis. Several studies have reported the predominance of additive gene action in controlling grain yield (Fan et al., 2008; Tian et al., 2015; Mosa et al., 2023; Mosa et al., 2024; **Mohamed, 2020**), although some reports also emphasize the role of non-additive gene effects (Mosa et al., 2010; Singh and Shahi, 2010; **Sadek *et al*., 2017**). Furthermore, GCA is widely used to estimate the breeding potential of inbred lines, where higher GCA effects typically indicate greater utility in producing high-yielding hybrids. Accordingly, the present study aimed to evaluate the general combining ability (GCA) of nine maize inbred lines and the specific combining ability (SCA) of their derived hybrids under two plant density levels and two nitrogen fertilization rates. The goal was to identify promising hybrids that exhibit tolerance to high planting density and adaptability across different environmental conditions (**Mansour *et al.*, 2024**).

2. Materials and Methods

The field study was conducted at Sakha Agricultural Research Station, affiliated with the Field Crops Research Institute, Egypt. A set of nine yellow maize inbred lines P1 (Sk 3), P2 (Sk 4), P3 (Sk B.C 16), P4 (GZ 658), P5 (Gm 1004), P6 (Cim/4-521), P7 (SK5006/2), P8 (Sk 5010/3), and P9 (Sk 5013/4) was selected based on their desirable general combining ability (GCA) and potential for high-density adaptation. During the summer season of 2023, a half-diallel mating design was implemented to generate 36 single-cross hybrids. These hybrids, along with two commercial checks (SC168 and SC178), were evaluated in 2024 for their performance in grain yield per hectare and grain yield per plant, standardized at 15.5% grain moisture. The evaluation was carried out under two plant densities: D1 = 59,524 plants/ha (recommended standard in Egypt), D2 = 83,333 plants/ha (high density), and two nitrogen fertilization rates: N1 = 286 kg N/ha (recommended rate), N2 = 400 kg N/ha (enhanced level). A split-split plot design with three replications was used. The nitrogen levels (N) were assigned to the main plots, plant densities (D) to the sub-plots, and the 38 maize entries (36 hybrids + 2 checks) to the sub-sub plots. Each experimental plot consisted of a single 6-meter-long row, with row spacing of 0.8 meters. The spacing between hills was 21 cm in D1 and 15 cm in D2. Standard agronomic practices were followed throughout the growing season. Nitrogen fertilizer, whether 286 or 400 kg N/ha was applied in two equal doses: the first half at the first irrigation, and the second at the second irrigation.

Statistical analysis of variance (ANOVA) was performed according to the method of Snedecor and Cochran (1989) using SAS software (SAS Institute, 2008). The GCA and SCA effects and associated mean squares were estimated following Griffing's Method 4, Model I (fixed effects) (Griffing, 1956). Variance components and combining ability estimates were computed using AGD-R software (version 5.0) developed by Rodriguez et al. (2015). The relative contribution of additive (K^2GCA) and non-additive (K^2SCA) gene action was assessed based on the formula of Baker (1978), with modifications as described by Hung and Holland (2012).

3. Results and Discussion

The analysis of variance (Table 1) revealed that the main effects of nitrogen levels (N) and plant densities (D) were highly significant ($P \leq 0.01$) for both grain yield per hectare and grain yield per plant. This indicates that both nitrogen fertilization and plant density had a strong and consistent influence on these two traits.

Significant mean squares due to hybrids (H) also demonstrated that genetic differences among the 38 evaluated maize hybrids were substantial for both yield-related traits. In contrast, the interaction terms D × N, H × N, and H × N × D were not statistically significant, suggesting that the combined effects of these factors did not markedly influence the expression of grain yield traits. However, the H × D interaction was significant for grain yield per plant, indicating that hybrid performance in terms of yield per plant varied depending on the planting density.

These findings align with previous research. For instance, **AL-Naggar *et al.*** (**2017**) reported that grain yield was significantly influenced by both nitrogen and density, while their interaction was not significant. **Mahmoud** (**2021**) observed significant variation among hybrids for both grain yield per unit area and per plant and also noted a significant hybrid × density interaction for grain yield per plant. Similarly, **Arfa** (**2012**) found that hybrid × nitrogen interaction had no significant effect on grain yield.

Table 1. Analysis of variance for nitrogen levels (N), plant densities (D), hybrids (H) and their interactions for grain yield/hectare and grain yield/plant.

SOV	d.f	Grain yield/hectare	Grain yield /plant
Rep.	**2**	17.31	2526.12
N	**1**	60.83**	14402.94**
Error a	**2**	2.55	1417.52
D	**1**	232.76**	25232.02**
D×N	**1**	0.52	5.72
Error b	**4**	2.48	2294.77
H	**37**	31.81**	7090.18**
H×N	**37**	1.06	398.93
H×D	**37**	1.47	1532.67**
H×D×N	**37**	0.73	473.72
Error c	**296**	1.55	625.26

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

As illustrated in Figure 1, increasing the nitrogen application rate from 286 kg N/ha (N1) to 400 kg N/ha (N2) resulted in a significant enhancement in both grain yield per hectare and grain yield per plant. Specifically, grain yield/ha improved by 8.8%, while grain yield per plant increased by 7.60%, indicating a positive response of maize to elevated nitrogen inputs. These findings are consistent with previous studies, which have demonstrated that higher nitrogen availability contributes to improved yield performance. For instance, **Arfa (2008), Mosa *et al.* (2010), and Abd El-Atty *et al*. (2019)** all reported that increasing nitrogen fertilization rates led to significant gains in maize grain yield under various environmental conditions.

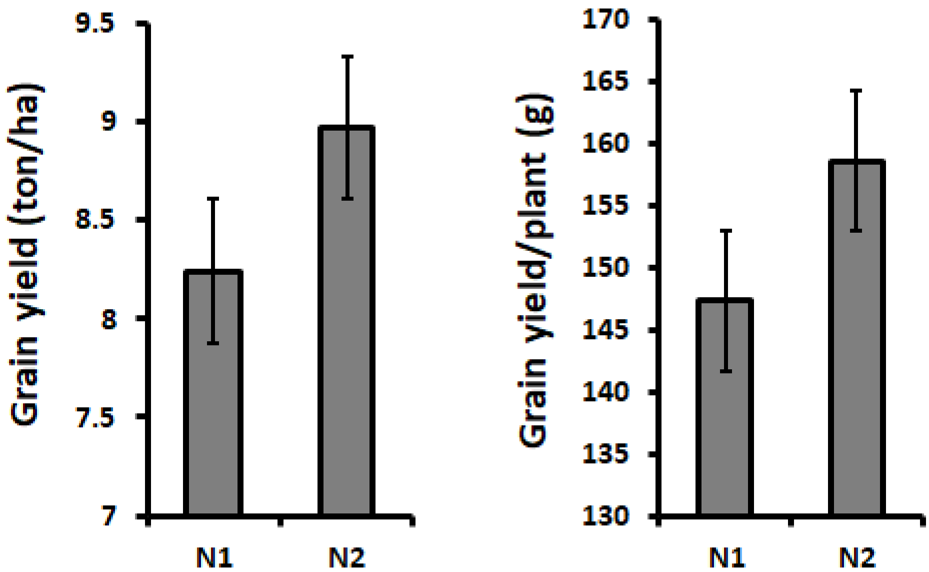

Fig. 1. Effect of nitrogen levels on grain yield (t/ ha) and grain yield/ plant (g).

In this study, the planting density of 59,524 plants/ha (D_1) was considered the non-stress environment, while 83,333 plants/ha (D_2) represented the stress environment. As shown in Figure 2, increasing plant density from D_1 to D_2 resulted in a significant 18.12% increase in grain yield per hectare, indicating that the higher density improved total yield productivity. Conversely, grain yield per plant decreased by 9.28% under the higher plant density, reflecting the expected reduction in individual plant performance due to increased inter-plant competition. These findings are in agreement with those of **Widdicombe and Thelen (2002)**, who reported increased grain yield as plant density rose from 56,000 to 90,000 plants/ha. Similarly, **Mahmoud (2021)** observed a noticeable decline in grain yield per plant as planting density increased from 48,000 to 72,000, 95,000, and 119,000 plants/ha, with reductions of 5.56%, 23.19%, and 23.71%, respectively. Further analysis of yield performance across different environmental combinations is presented in Figure 3. The highest grain yield per hectare was recorded in the D_2N_2 environment (high density and high nitrogen level), followed by D_2N_1. In contrast, the D_1N_1 environment (low density and low nitrogen) produced the lowest grain yield/ha. This indicates that D_2N_2 was the most favorable condition for maximizing yield per unit area. For grain yield per plant, the optimal environment was D_1N_2 (lower density with high nitrogen), which achieved the highest value, while D_2N_1 resulted in the lowest yield per plant. These results suggest that maximizing individual plant productivity requires reduced plant competition coupled with sufficient nitrogen supply. These outcomes support earlier findings by **Al-Kaisi and Yin (2003)**, who noted that optimal yield environments often correspond to higher plant densities. Likewise, **Abd El-Aty *et al.* (2019)** reported that the highest grain yield was obtained at D_2N_2 (84,341 plants/ha with 357 kg N/ha), while the lowest was at D_1N_2 (59,351 plants/ha with 286 kg N/ha), aligning closely with the present findings.

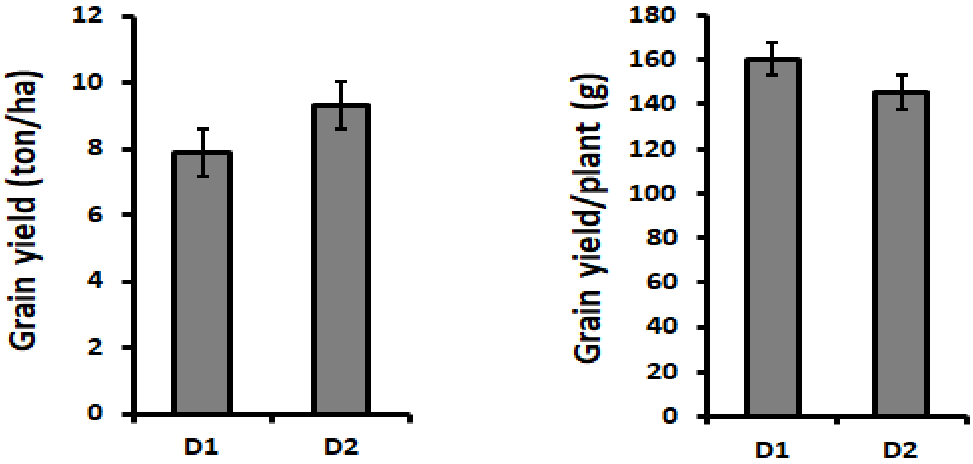

Fig. 2. Effect of plant densities on grain yield (t/ ha) and grain yield/ plant (g).

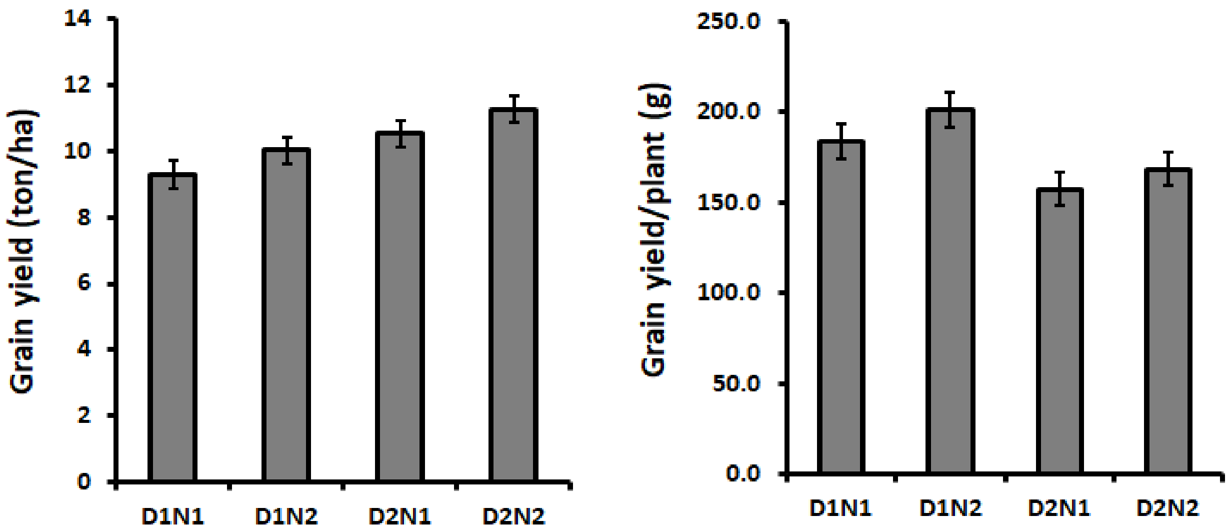

Fig. 3. Means of for environments; D_1N_1, D_1N_2, D_2N_1 and D_2N_2 for grain yield/ ha and grain yield/plant.

The average performance of the 36 maize hybrids across two nitrogen levels and two planting densities, along with their percentage of superiority over the commercial checks, is presented in Table 2. For grain yield per hectare, the highest-performing hybrid was P2 × P8 (11.53 t/ha), followed by P3 × P8 (11.08 t/ha), P3 × P7 (10.86 t/ha), P2 × P9 (10.48 t/ha), and P5 × P8 (10.47 t/ha). In contrast, the hybrid P5 × P6 recorded the lowest grain yield at 4.92 t/ha. The wide yield range of 6.61 t/ha highlights substantial genetic variation, offering valuable opportunities for selection. Similarly, for grain yield per plant, the hybrid P2 × P8 also ranked first with 196.97 g, followed by P3 × P8 (190.95 g), P3 × P7 (187.67 g), P2 × P9 (185.65 g), and P5 × P8 (180.69 g). The lowest yield per plant was again observed for P5 × P6 (100.36 g), with a range of 96.61 g, reflecting notable variability suitable for selection. In terms of superiority percentage, the top five hybrids P2 × P8, P3 × P8, P3 × P7, P2 × P9, and P5 × P8—significantly outperformed the commercial checks SC168 (8.64 t/ha and 156.6 g) and SC178 (9.01 t/ha and 160.29 g) in both traits. Further comparison of hybrid performance across planting densities is shown in Figure 4, where grain yield per hectare under the non-stress environment (D1 = 59,524 plants/ha) was plotted against yield under the stress environment (D2 = 83,333 plants/ha). Hybrids No. 1, 3, 7, 10, 13, 14, 15, 16, 19, 20, 21, 24, 26, 29, 32, and 36 exhibited consistently high yields in both environments. Figure 5 shows that most of these hybrids also maintained high grain yield per plant under both densities, except for hybrids No. 3, 16, and 26, which showed a relative decline in individual plant performance under stress. Among these, hybrids P2 × P8 (No. 14), P3 × P8 (No. 20), P3 × P7 (No. 19), P2 × P9 (No. 15), P5 × P8 (No. 29), and P8 × P9 (No. 36) identified as the most stable and tolerant performers across both environments, making them promising candidates for advancement in breeding programs targeting high plant density tolerance.

These findings are consistent with the results of **Kamara *et al.* (2006)**, who reported that maize hybrids achieved higher grain yields under dense planting (88,888 plants/ha) compared to lower densities (53,333 plants/ha), and that a subset of hybrids significantly outperformed others under both density levels.

Table 2. Superiority % of 36 hybrids relative to SC 168 and SC 178 for grain yield (t/ha) and grain yield / plant(g), across all environments.

Hybrid	NO	Grain yield (t/ha)			Grain yield / plant(g)		
		Mean	Superiority% relative to checks		Mean	Superiority% relative to checks	
			SC 168	SC 178		SC 168	SC 178
P1×P2	1	9.79	13.31	8.65	167.06	6.67	4.22
P1×P3	2	8.81	1.96	-2.21	153.21	-2.16	-4.41
P1×P4	3	9.13	5.67	1.33	156.61	6.38	-2.29
P1×P5	4	5.26	-39.12**	-41.62**	91.58	-41.51**	-42.86**
P1×P6	5	7.45	-13.77	-17.31	131.01	-16.34*	-18.26**
P1×P7	6	8.02	-7.17	-10.98*	145.01	-7.40	-9.53
P1×P8	7	10.42	20.48**	15.53**	176.14	12.47	9.88
P1×P9	8	8.59	-0.69	-4.77	150.99	-3.58	-5.80
P2×P3	9	8.66	0.23	-3.88	157.94	0.85	-1.46
P2×P4	10	9.97	15.39**	10.74	174.64	11.51	8.95
P2×P5	11	7.75	-10.30	-13.98**	141.20	-9.83	-11.90
P2×P6	12	6.62	-23.49**	-26.63**	125.84	-19.64**	-21.49**
P2×P7	13	9.27	7.29	2.88	162.13	3.53	1.14
P2×P8	14	11.53	33.33**	27.85**	196.97	25.77**	22.88**
P2×P9	15	10.48	21.29**	16.31**	185.65	18.55**	15.82
P3×P4	16	9.44	9.25	4.77	162.03	3.46	1.08
P3×P5	17	6.96	-19.56**	-22.86**	119.95	-23.40**	-25.16**
P3×P6	18	8.42	-2.54	-6.54	158.32	1.09	-1.22
P3×P7	19	10.86	25.57**	20.42**	187.67	19.84**	17.08**
P3×P8	20	11.08	28.12**	22.86**	190.95	21.93**	19.12**
P3×P9	21	10.14	17.36**	12.54**	177.86	13.57	10.96
P4×P5	22	7.93	-8.12	-11.98**	138.97	-11.25	-13.30
P4×P6	23	5.33	-38.42**	-40.95**	113.22	-27.70**	-29.36**
P4×P7	24	8.89	2.77	-1.44	157.09	0.31	-1.99
P4×P8	25	7.14	-17.47**	-20.86**	124.84	-20.28**	-22.11**
P4×P9	26	9.04	4.62	0.33	155.85	-0.47	-2.76
P5×P6	27	4.92	-43.05**	-45.39**	100.36	-35.91**	-37.38**
P5×P7	28	8.13	-6.01	-9.87	147.52	-5.79	-7.96
P5×P8	29	10.47	21.18**	16.20**	180.69	15.38*	12.72*
P5×P9	30	9.04	4.62	0.33	153.23	-0.21	-4.40
P6×P7	31	5.92	-31.48**	-34.29	129.96	-17.01**	-18.92**
P6×P8	32	9.23	6.82	2.44	159.43	1.80	-0.53
P6×P9	33	6.89	-20.25**	-23.52**	131.81	-15.83*	-17.76**
P7×P8	34	8.96	3.70	-0.55	156.45	-0.09	-2.39
P7×P9	35	8.98	3.93	-0.33	155.54	-0.67	-2.96
P8×P9	36	10.08	16.66**	11.87	177.63	13.42*	10.81
LSD 0.05		1.00			20.00		
0.01		1.31			26.33		

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

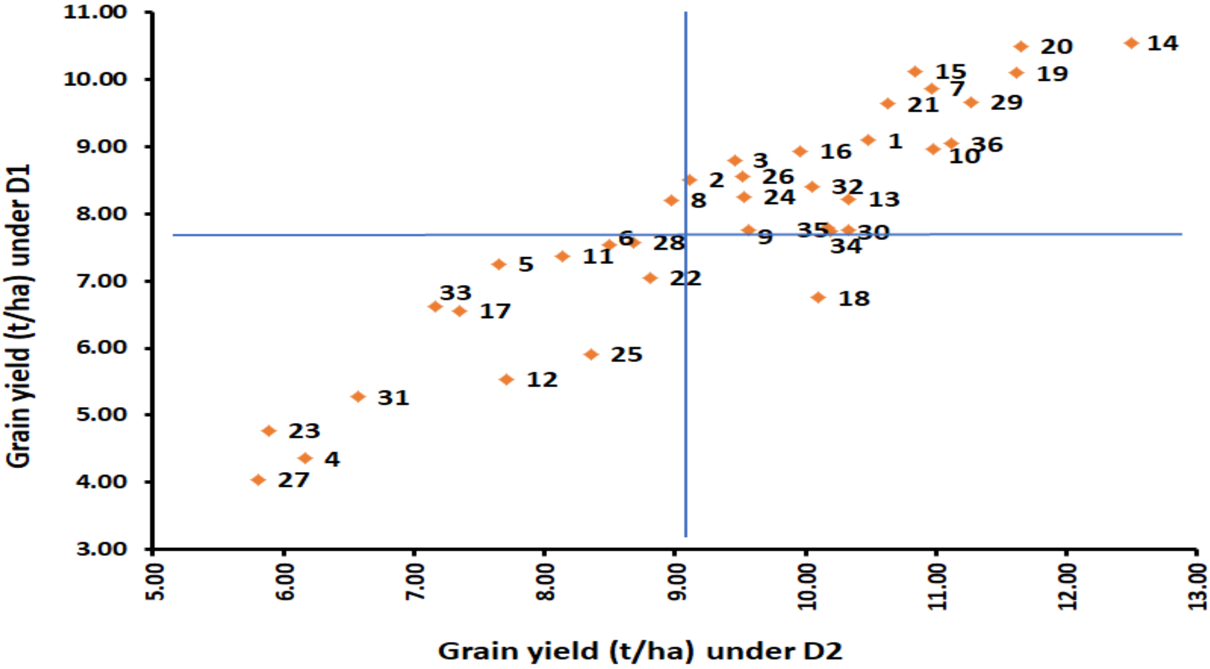

Fig. 4. Means grain yield (t/ ha) of 36 hybrids under (D_1) against their means under (D_2) across nitrogen levels.

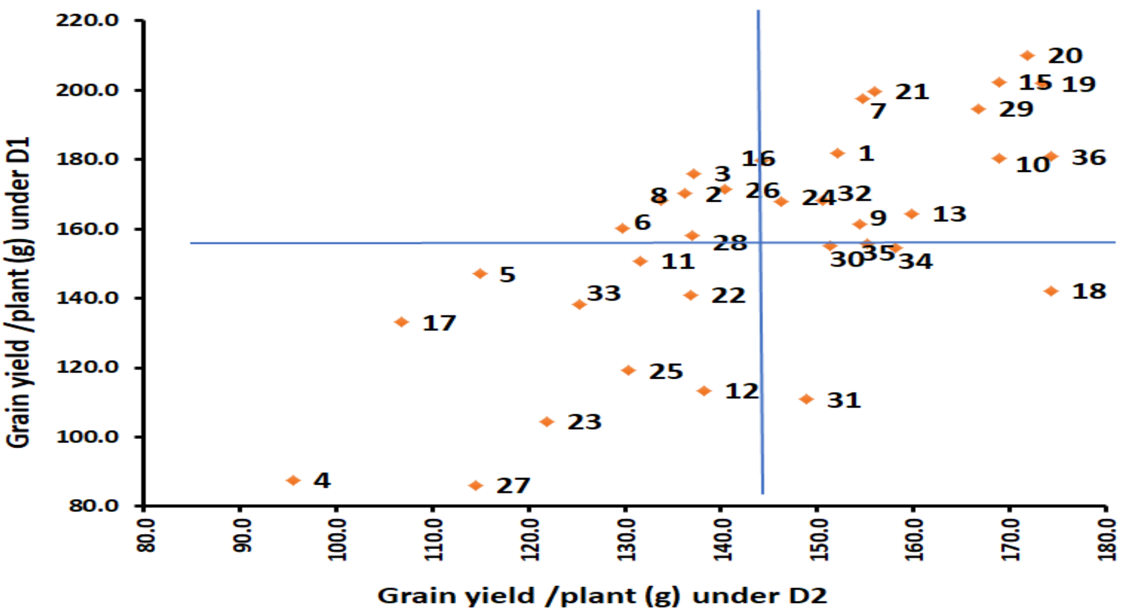

Fig. 5. Means grain yield/ plant (g) of 36 hybrids under (D_1) against their means under (D_2) across nitrogen levels.

The analysis of variance results, as presented in Table 3, revealed that the mean squares associated with both general combining ability (GCA) and specific combining ability (SCA) were highly significant ($P \leq 0.01$) for grain yield per hectare and grain yield per plant. These findings indicate that both additive and non-additive genetic effects were substantially involved in the inheritance of these yield-related traits across the tested environmental conditions. However, the result exhibited that the ratio between twice the k2GCA component to total genetic effects (2K2GCA + K2SCA) was 0.67 and 0.65 for grain yield / ha and grain yield/ plant, respectively, meaning that additive gene effects were more important than non-additive gene effects in controlling these traits and that there is a scope for improvement of trait by selection. These findings agree with earlier studies by **Fan *et al.* (2008)**, **Pswarayi and Vivek (2008)**, **Tian *et al.* (2015)**, **Dong *et al.* (2022)**, and **Mosa *et al.* (2023,**

2024), all of whom reported a greater contribution of additive over non-additive effects in controlling grain yield.

The interaction analysis revealed that most combinations between GCA and SCA with nitrogen levels and plant densities including GCA × N, SCA × N, GCA × D × N, and SCA × D × N—were not statistically significant for either grain yield per hectare or grain yield per plant. This indicates that these genetic effects were generally stable across varying nitrogen conditions and their combined effects with plant density and nitrogen. However, both GCA × D and SCA × D interactions exhibited significant effects for grain yield per plant, suggesting that plant density influenced the expression of both additive and non-additive gene actions for this trait. This highlights the importance of evaluating hybrid performance under multiple plant density levels, particularly when selecting targets traits at the individual plant level.

Similar findings were reported by **AL-Naggar *et al.*** (**2017**) and **Abd El-Atty *et al.* (2019)**, who noted significant interactions of GCA with plant density and SCA with nitrogen level for grain yield, indicating the importance of evaluating combining ability under varying environmental conditions.

Table 3. analysis of variance for General Combining Ability (GCA), Specific Combining Ability (SCA), and their Interactions with Nitrogen Levels (N) and Plant Densities (D) for Grain Yield per Hectare and Grain Yield per Plant

S.O.V	d.f	Grain yield /hectare	Grain yield /plant
GCA	8	96.85**	20524.58**
SCA	27	14.81**	3603.65**
GCA×N	8	0.73	394.51
SCA×N	27	1.21	383.79
GCA×D	8	1.51	3442.06**
SCA×D	27	1.40	949.04*
GCA×D×N	8	1.61	479.77
SCA×D×N	27	0.50	501.94
Error	280	1.58	632.66
$2K^2GCA \backslash 2K^2GCA+K^2SCA$		0.67	0.65

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

The general combining ability (GCA) effects for the nine maize inbred lines, assessed across two nitrogen regimes and two planting densities, are summarized in Table 4. The results identified four inbred lines P2, P3, P8, and P9 as having desirable positive and significant GCA effects for both grain yield per hectare and grain yield per plant. This indicates that these lines possess favorable additive gene contributions toward improving grain yield under varying environmental conditions. The consistency of their performance across both traits suggests that either grain yield per hectare or grain yield per plant can serve as a reliable indicator for selecting superior general combiners in maize breeding programs aimed at enhancing yield potential under high plant density and nitrogen variation.

Table 4. General Combining Ability (GCA) Estimates for Nine Maize Inbred Lines Evaluated Across Two Nitrogen Levels and Two Plant Densities for Grain Yield per Hectare and per Plant

Inbred line	Grain yield / hectare	Grain yield / plant
P1	-0.190	-7.082**
P2	0.753**	12.893**
P3	0.795**	12.392**
P4	-0.276*	-5.421*
P5	-1.190**	-21.096**
P6	-2.002**	-24.462**
P7	0.0033	2.883
P8	1.442**	20.272**
P9	0.634**	9.622**
LSD g_i 0.05	0.25	5.07
0.01	0.33	6.67
LSDg_i-g_j 0.05	0.38	7.60
0.01	0.49	10.01

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

The top-performing hybrids in terms of SCA contributions to grain yield per hectare and grain yield per plant totaled 12 and 7, respectively, as shown in Table 5. The crosses P1 × P4, P2 × P4, P3 × P6, P3 × P7, P4 × P5, P5 × P7, and P5 × P8 demonstrated notably favorable specific combining ability values for both traits. These results suggest that these hybrids possess valuable non-additive genetic potential and merit further advancement in maize improvement programs

Table 5. Specific combining ability (SCA) estimates for 36 maize hybrids, evaluated under two nitrogen application rates and two plant population densities, for both grain yield per hectare and per plant.

Hybrid		Grain yield/ hectare	Grain yield/ plant
P1×P2		0.626*	8.597
P1×P3		-0.392	-4.746
P1×P4		0.995**	16.459**
P1×P5		-1.958**	-32.886**
P1×P6		1.041**	9.907
P1×P7		-0.421	-3.434
P1×P8		0.566	10.299
P1×P9		-0.458	-4.197
P2×P3		-1.485**	-19.989**
P2×P4		0.891**	14.523*
P2×P5		-0.409	-3.242
P2×P6		-0.733*	-15.244*
P2×P7		-0.113	-6.289
P2×P8		0.729*	11.157
P2×P9		0.493	10.486
P3×P4		0.320	2.409
P3×P5		-1.248**	-23.993**
P3×P6		1.028**	17.742**
P3×P7		1.428**	19.743**
P3×P8		0.241	5.637
P3×P9		0.107	3.195
P4×P5		0.799*	12.842*
P4×P6		-0.993**	-9.544
P4×P7		0.530	6.977
P4×P8		-2.629**	-42.664**
P4×P9		0.083	-1.003
P5×P6		-0.483	-6.728
P5×P7		0.685*	13.088*
P5×P8		1.616**	28.867**
P5×P9		0.997**	12.053
P6×P7		-0.707*	-1.110
P6×P8		1.188**	10.976
P6×P9		-0.340	-5.999
P7×P8		-1.115**	-19.355**
P7×P9		-0.286	-9.618
P8×P9		-0.597	-4.918
LSD S_{ij}	0.05	0.61	12.32
	0.01	0.81	16.22
LSD S_{ij}-S_{kl}	0.05	0.85	17.01
	0.01	1.11	22.38

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

4. **Conclusion**

The results of this study demonstrated that increasing nitrogen levels from N_1 to N_2 led to significant improvements in grain yield per hectare and grain yield per plant. Similarly, elevating plant density from D_1 to D_2 significantly enhanced grain yield per hectare, although it caused a reduction in grain yield per plant due to increased inter-plant competition. The genetic evaluation indicated that additive genetic effects contributed more substantially than non-additive ones to the expression of grain yield per hectare and per plant. This finding supports the use of selection programs that exploit additive variance as an efficient approach for improving these traits. Among the inbred lines assessed, P2, P3, P8, and P9 consistently exhibited favorable general combining ability (GCA) estimates under various environmental conditions, highlighting their breeding potential and suitability as parental lines in hybrid maize development. Notably, five hybrids particularly under high-density conditions consistently outperformed the commercial checks (SC168 and SC178) in both grain yield per hectare and per plant across all tested environments. These superior hybrids represent promising candidates for advancement in maize breeding programs targeting high planting density tolerance and enhanced grain yield.

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