RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
58 (4) 1609-1619, 2026
http://doi.org/10.54910/sabrao2026.58.4.13
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

MULTI-TRAIT SELECTION OF MAIZE (*ZEA MAYS* L.) HYBRIDS UNDER NORMAL AND HIGH PLANTING DENSITIES

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SUMMARY

Limited arable and productive soil is the primary hindrance to increasing maize production, requiring appropriate selection of genotypes and planting density combinations. The present study aimed to evaluate maize hybrids' responses under normal and high planting densities, genetic parameters, and trait correlations, as well as identify the adaptive hybrids. The two separate experiments comprised normal (53.333 plants ha^{-1}) and high (83.333 plants ha^{-1}) planting densities, carried out during 2023–2024. Each experiment layout was in an augmented randomized complete block design, involving 23 maize genotypes comprising 19 hybrids and four check cultivars replicated three times. The results showed the high planting density produced 1.46 t ha^{-1} higher yield than the normal planting density, with G8 and G4 as the high-yielding candidate hybrids across both densities. Leaf angle and grain yield exhibited the highest genotypic and phenotypic coefficients of variation and broad-sense heritability. Anthesis-silking interval, leaf angle, and shelling percentage showed significant correlations with grain yield under normal planting density. The MGIDI (multi-trait genotype-ideotype distance index) selected hybrids G4, G8, and G15 under normal planting density; G11, G2, and G9 under high planting density; and G20 and G23 under both densities. Identifying maize hybrids suitable for higher planting densities may support breeding efforts to develop efficient and high-yielding genotypes.

Keywords: Maize hybrids, genetic parameters, correlation, MGIDI, adaptability, planting density

Key findings: Maize (*Z. mays* L.) traits, such as anthesis-silking interval, leaf angle, and shelling percentage, showed a significant correlation with grain yield under normal planting density. MGIDI-based multivariate selection identified five maize hybrids as potential candidates for improving productivity under normal and high planting densities.

Communicating Editor: Dr. Kamile Ulukapi

Manuscript received: December 21, 2025; Accepted: June 13, 2026.

Citation: Yanti AI, Marwiyah S, Suwarno WB (2026). Multi-trait selection of maize (*Zea mays* L.) hybrids under normal and high planting densities. *SABRAO J. Breed. Genet. 58 (4) 1609-1619. http://doi.org/10.54910/sabrao2026.58.4.13*.

INTRODUCTION

Maize (*Zea mays* L.) is one of the world's most important cereal crops adapted to diverse environmental conditions. In Indonesia, the dried shelled corn production increased from 14.77 million tons in 2023 to 15.14 million tons in 2024 (BPS, 2025). For animal feed, expectations for the corn demand to increase are from 9.8 million tons in the 2024/25 marketing year to 9.9 million tons in the 2025/26 marketing year in Indonesia (USDA, 2025). The adoption of appropriate planting systems, such as planting space modification and increasing planting density, is essential to meet all these demands (Dong *et al.,* 2022). Furthermore, achieving higher yields can succeed through the development of maize genotypes tolerant and adaptive to high planting densities.

High planting density stress induces considerable variations in several earliness, growth, and yield-related traits, such as extending the anthesis-silking interval, increasing plant height, reducing stem diameter, and leaf area per plant (Sher *et al.*, 2017). Likewise, it decreases ear length, grains per ear, and thousand-kernel weight (Tang *et al.,* 2018). Nevertheless, an adaptive maize genotype must be able to maintain its productivity even under abiotic stress conditions. Suwardi *et al.* (2021) reported various maize hybrids showed increased yield as the plant population rose, with a density of 71.428 plants ha^{-1}, yielding 8.34 t ha^{-1}, and 83.333 plants ha^{-1} yielded 9.78 t ha^{-1}. Efendi *et al.* (2021) reported many maize hybrids with 83.333 plants ha^{-1} were able to produce a grain yield of 8.43–9.90 t ha^{-1}. Therefore, determining the optimal planting density requires the consideration of genotype-by-environment interaction and the use of stress-responsive genotypes (Assefa *et al.,* 2016).

Identification of traits contributing to improved yield at planting density can be successful through the correlation analysis. Traits showing significant positive and negative associations with grain yield can provide information for determining selection criteria (Priyanto *et al.,* 2023). Leaf angle is one of the crucial growth traits in selecting maize genotypes under the high planting density. Most acute leaf angles were identical to more upright leaves, improving canopy light distribution, photosynthetic efficiency, and stress tolerance, thereby supporting a higher grain yield (Cao *et al.,* 2022).

The performance of genotype selection based on several essential traits simultaneously can use the MGIDI (multi-trait genotype-ideotype distance index) (Olivoto and Nardino, 2021). This index is reliant on factor analysis and ideotype, with an option to apply different weights for each trait. This approach also identifies the strengths and weaknesses of each genotype through factor analysis, allowing for more precise selection as per desired criteria (Azrai *et al.,* 2023). Selection based on MGIDI has been applicable in maize genotype selection under optimum and acidic soil conditions (Zendrato *et al.*, 2024) and multiple environments (Azrai *et al.*, 2023). However, limited information is available on the simultaneous evaluation and multi-trait selection of tropical maize hybrids under contrasting planting densities, particularly using the MGIDI approach to identify density-adaptive genotypes. The presented study aimed to investigate the response of maize hybrids under normal and high planting densities, estimate the genetic parameters, and analyze the correlations among various traits. It also sought to identify the potential hybrids through the MGIDI under normal and high planting densities.

MATERIALS AND METHODS

Experimental site and conditions

The concerned research on maize (*Z. mays* L.) commenced from December 2023 to March 2024 at the Leuwikopo Experimental Station, IPB University, Bogor, Indonesia. During the experiment, the average temperature ranged from 26.26 to 27.18 °C. Total monthly rainfall ranged from 232.80 to 723.20 mm, accompanied by humidity reaching 80.00–86.35% and sunshine duration (3.84–6.58 hours per day). These conditions were generally suitable for maize growth, as the recorded temperature was close to the optimal range of 28–30 °C and the growing season rainfall requirement was 400–800 mm (Kumar *et al.*, 2021; Madamombe *et al.*, 2025). Obtaining climate data was from the West Java Climatological Station (BMKG, 2024). The experimental field soil type was alluvial.

Genetic materials and experimental design

The genetic materials used comprised 19 candidate hybrids, including P55/L26 (G1), P75/P2A (G2), B2/Mr14 (G3), L15/L26 (G4), B2/P2A (G5), H1/P42 (G6), L26/B1 (G7), L26/B4B (G8), B2/P42 (G9), L26/Mr14 (G10), L42/P42 (G11), L28/P2A (G12), L15/B4B (G13), P9/P2A (G14), L28/L15 (G15), L28/P42 (G16), L22/B1 (G17), L6/P2A (G18), and P75/P42 (G19). The four check cultivars included BISI 18 (G20), JHG 02 (G21), P27 (G23), and NK Perkasa (G24). BISI 18 is a broadly adapted variety, P27 and NK Perkasa are high yielding, and JHG 02 easily adapts to waterlogging. Two separate experimental designs consisted of the normal planting density (ND = 53.333 plants ha^{-1}), with a spacing of 75 cm × 25 cm, and the high planting density (HD = 83.333 plants ha^{-1}), with a spacing of 60 cm × 20 cm. Each experiment layout was in an augmented randomized complete block design with four check cultivars repeated three times. Fertilization took place in three stages, i.e., at seven days after planting (DAP) using 150 kg ha^{-1} urea and 350 kg ha^{-1} NPK Mutiara 16-16-16. The second was at 28 DAP using 150 kg ha^{-1} urea, and the third was at 36 DAP using 61 kg ha^{-1} urea. The crop management practices applied in this experiment included irrigation, weeding, and pest and disease control. Harvesting occurred at 100 days after planting.

Trait measurements and data collection

In each experimental subplot, using five randomly selected plants enabled the observation of agronomic traits and yield components, following the guidelines by Efendi (2021). The observed traits included days to anthesis, anthesis-silking interval (ASI) (day), leaf angle (°), ear length (cm), ear diameter (mm), the number of kernel rows per ear, the number of kernels per row, ear aspect, and shelling percentage (%). The calculation of 1000-kernel weight (TGW, g) at 15% moisture content used the following formula:

$$\mathrm{TGW\ (g)} = \left(\frac{100 - \mathrm{MC}}{100 - 15}\right) \times \mathrm{HGW} \times 10$$

Where MC is the actual moisture content of the harvested grain (%), and HGW is the 100-kernel weight (g). Grain yield (t ha^{-1}) at 15% moisture content calculation had the following formula:

$$\mathrm{Yield\ (t\ ha^{-1})} = \frac{10{,}000}{\mathrm{PS}} \times \left(\frac{100 - \mathrm{MC}}{100 - 15}\right) \times \frac{\mathrm{EW}}{1000} \times \mathrm{SP}$$

Where PS is the harvested plot size (m^2), MC is the actual moisture content of the harvested grain (%), EW is the ear yield per plot (kg), and SP is the shelling percentage (%).

Statistical analyses

The collected data underwent a combined analysis of variance (ANOVA) across two planting densities to evaluate the effects of planting density, candidate maize hybrids, check cultivars, and their interactions. Estimates also included genetic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and broad-sense heritability on an entry-mean basis. The categories of GCV and PCV were narrow (<10%), moderate (10%–20%), and broad (>20%) (Sivasubramanian and Menon, 1973). Heritability categorization was low (<0.2), moderate (0.2–0.5), and high (>0.5) (Stansfield, 1991). Pearson correlation coefficient sought to evaluate the association among various earliness, growth, and yield-related traits. Maize hybrid selection, as performed, used the MGIDI by Olivoto and Nardino (2021) based on five traits (ASI, leaf angle, ear aspect, shelling percentage, and grain yield) at a 20% selection proportion. The study applied an equal weight to the five traits because they were considerably equal in their importance. The use of SAS on Demand for

Table 1. Combined analysis of variance for agronomic traits, yield components, and grain yield in maize.

Sources	d.f.	DTA	LA	EL	ED	NER	NKR	SP	TGW	GY
Density (P)	1	1.42^{ns}	6.16^{ns}	8.40^{**}	29.06^{*}	0.33^{ns}	11.35^{ns}	14.46^{*}	594.30^{ns}	21.26^{*}
Rep/Density	4	1.17^{ns}	8.70^{ns}	0.35^{ns}	3.08^{ns}	0.46^{ns}	2.19^{ns}	1.64^{ns}	3620.04^{*}	1.66^{ns}
Candidate (V)	18	1.25^{ns}	52.98^{**}	4.40^{ns}	7.93^{**}	4.08^{**}	26.85^{**}	11.61^{**}	3970.32^{**}	8.39^{**}
Check (C)	3	4.46^{**}	10.05^{ns}	5.93^{ns}	9.41^{*}	9.15^{**}	4.85^{ns}	8.56^{ns}	254.03^{ns}	26.61^{**}
V vs C	1	0.77^{ns}	457.43^{**}	18.60^{**}	0.87^{ns}	2.21^{ns}	181.85^{**}	62.30^{**}	12.30^{ns}	125.47^{**}
V x P	18	0.58^{ns}	10.25^{ns}	0.98^{ns}	3.61^{ns}	0.61^{ns}	4.82^{ns}	13.89^{**}	2582.99^{*}	0.92^{ns}
C x P	3	1.06^{ns}	11.60^{ns}	2.57^{ns}	1.74^{ns}	0.57^{ns}	7.02^{ns}	6.58^{ns}	3301.10^{*}	9.85^{*}
(V vs C) x P	1	0.56^{ns}	0.99^{ns}	2.01^{ns}	0.15^{ns}	0.25^{ns}	0.37^{ns}	3.33^{ns}	341.49^{ns}	3.46^{ns}
Error	11	0.73	8.73	1.91	1.77	0.68	2.89	2.70	875.33	1.94
CV (%)		1.50	11.44	7.74	2.75	5.29	4.46	2.10	9.29	18.60

DTA: days to anthesis; LA: leaf angle; EL: ear length; ED: ear diameter; NER: number of kernel rows per ear; NKR: number of kernels per row; SP: shelling percentage; TGW: 1000-kernel weight; GY: grain yield; **: significant at P < 0.01; *: significant at P < 0.05; ns: not significant at P > 0.05; d.f.: degrees of freedom; and CV: coefficient of variation.

Academics (welcome.oda.sas.com) assessed the combined ANOVA and adjusted means, whereas using Microsoft Excel 2021 estimated the genetic parameters and bar charts. Running Pearson correlation analysis, MGIDI, and selection differential engaged RStudio with the 'metan' R package (Olivoto and Lucio, 2020).

RESULTS AND DISCUSSION

Analysis of variance and hybrids' responses

The combined analysis of variance showed planting density had a significant effect on the traits of ear length, ear diameter, shelling percentage, and grain yield in maize (*Z. mays* L.) (Table 1). However, the nonsignificant effect of plant density was notable for leaf angle, with the same findings also a report from past studies on maize (Ygzaw *et al.*, 2025). The maize hybrids also remarkably affected the majority of the traits, except for days to anthesis and ear length. Maize check cultivars showed significant effects on days to anthesis, ear diameter, the number of kernel rows per ear, and grain yield. Overall, the average values of maize hybrids and check cultivars were different for leaf angle, ear length, the number of kernels per row, shelling percentage, and grain yield. The interactions of hybrids and planting density were substantial for shelling percentage and 1000-kernel weight. The nonsignificant interaction effects of hybrids and planting density on grain yield revealed that the maize hybrids' response was relatively at par. Cui *et al.* (2022) reported maize hybrids responded differently to various planting densities. The check cultivars and planting density interaction significantly influenced the 1000-kernel weight and grain yield. Meanwhile, the interaction between candidate hybrids and check cultivars (V vs. C) and the planting density was nonsignificant for all traits.

The analysis of variance of grain yield showed a significant effect on check cultivars and planting density interaction. Three check cultivars (BISI 18, P27, and NK Perkasa) yielded higher under high planting density (Figure 1). In contrast, the check genotype JHG02 experienced a yield reduction, appearing to be more suitable with the normal planting density. The results suggested maize cultivars responded differently to planting density, decreasing in low-tolerance cultivars and increasing in high-tolerance cultivars, with the same findings reported in past studies on the maize crop (Yu *et al.*, 2019; Wang *et al.*, 2025).

Increased planting density had a nonsignificant effect on the earliness traits, such as days to anthesis and anthesis-silking interval, and the traits had similar values under different planting densities (Table 2). Leaf angle, the number of kernel rows per ear, and

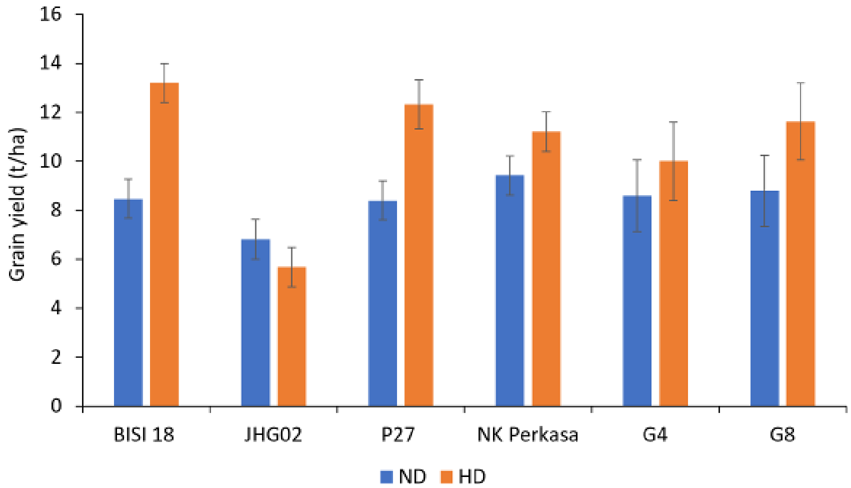

Figure 1. Response of check cultivars and candidate hybrids G4 and G8 to change in planting density on grain yield; ND: normal planting density; HD: high planting density.

Table 2. Means and differences of agronomic traits, yield components, and grain yield in maize under two planting densities.

Density	DTA (d)	ASI (d)	LA (°)	EL (cm)	ED (mm)	NER	NKR	SP (%)	TGW (g)	GY (t ha^{-1})
ND	56.5	0.3	27.48	18.08	49.00	15.8	38.0	78.44	316.70	6.21
HD	56.9	0.5	26.68	17.17	47.47	15.6	36.9	77.24	324.40	7.67
HD-ND	0.4^{ns}	0.2	-0.81^{ns}	-0.92^{**}	-1.53^{*}	-0.2^{ns}	-1.1^{ns}	-1.20^{*}	7.70^{ns}	1.46^{*}

ND: normal planting density; HD: high planting density; DTA: days to anthesis; ASI: anthesis-silking interval (not analyzed statistically); LA: leaf angle; EL: ear length; ED: ear diameter; NER: number of kernel rows per ear; NKR: number of kernels per row; SP: shelling percentage; TGW: 1000-kernel weight (at 15% moisture content); and GY: grain yield (at 15% moisture content).

the number of kernels per row had nonsignificant influences, showing a slight decrease under the high planting density. The traits of ear length, ear diameter, and shelling percentage exhibited a considerable decrease. Conversely, the 1000-kernel weight enhanced slightly; however, the effect was nonsignificant. Maize grain yield per hectare increased by 1.46 t ha^{-1}, ranging from 6.21 t ha^{-1} (normal planting density) to 7.67 t ha^{-1} (high planting density). The results further revealed that although the yield components per plant tended to decrease, the increased number of plants per hectare was able to compensate for this reduction. The results suggest that the anthesis-silking interval, leaf angle, 1000-kernel weight, the number of kernel rows per ear, and the number of kernels per row contributed to maintaining grain yield under the high planting density. These traits remained relatively stable despite a boost in plant competition. Previous studies have also reported an increase in maize grain yield per hectare under high density compared with low density. Said reports were 22.7% to 30.0% at 88.888 plants per hectare in Ghana (Ygzaw *et al.*, 2025) and 1.44 t ha^{-1} or around 17.3% at 83.333 plants per hectare in Gowa (Suwardi *et al.,* 2021).

Adjusted mean values of the studied maize genotypes for various traits at both planting densities showed hybrid G14 flowered earlier, and G6 had a relatively smaller anthesis-silking interval (ASI) (Table 3). These traits also emerged to be important contributors to maize hybrids tolerant to high planting density (Al-Naggar *et al.,* 2015). Hybrid G13 had the smallest leaf angle

Table 3. Adjusted mean of agronomic traits, yield components, and grain yield in maize across normal and high planting densities.

Hybrids	DTA (d)	ASI (d)	LA (°)	EL (cm)	ED (mm)	NER	NKR	SP (%)	TGW (g)	GY (t ha^{-1})
Candidate hybrids										
G1	57.2	-0.1	26.72	19.05	48.71	18.1	38.4	76.62	301.94	4.69
G2	56.5	-0.1	32.75	17.37	48.50	15.5	35.0	80.39	405.42	8.30
G3	55.8	1.0	26.59	17.42	45.92	13.0	39.1	75.63	335.79	7.41
G4	57.2	0.4	26.11	19.76	46.73	15.7	41.7	79.01	318.04	9.13
G5	56.8	2.5	30.76	14.06	45.32	14.9	32.8	76.54	247.07	3.49
G6	57.3	0.5	24.12	14.04	49.22	15.2	30.0	77.73	274.35	6.57
G7	56.5	-0.1	26.28	16.62	51.92	17.1	34.2	79.40	451.51*+	4.62
G8	55.8	0.0	27.08	19.77	50.47	18.0	36.3	75.42	320.31	9.73
G9	56.5	0.4	25.83	16.26	45.16	15.1	36.5	79.22	338.58	7.51
G10	55.8	0.0	26.09	18.67	49.39	16.4	36.7	76.68	341.83	7.12
G11	57.0	0.0	29.69	17.66	48.96	15.4	38.2	78.76	268.80	7.46
G12	55.5	1.7	35.13	17.35	49.01	15.3	41.9	76.18	331.81	3.21
G13	58.7	1.4	20.79	18.88	46.41	15.1	44.2	76.59	310.62	7.57
G14	55.0	1.0	42.81	17.10	50.61	15.6	32.9	75.15	321.71	3.40
G15	56.5	-0.5	21.96	18.38	49.63	16.4	41.4	81.02	360.04	5.96
G16	57.7	0.4	31.38	17.19	47.86	18.5	36.9	83.26*+	324.96	7.43
G17	57.2	0.4	30.88	17.43	48.52	15.3	32.1	74.50	315.43	5.32
G18	57.7	0.9	21.34	16.84	44.74	13.9	37.2	75.07	261.16	3.35
G19	56.7	-0.6	22.71	16.68	49.97	16.7	32.6	77.59	334.23	8.34
Check cultivars										
BISI 18	56.7	-0.2	22.09	19.47	47.20	15.5	40.9	81.09	323.00	10.83
JHG02	56.5	1.2	21.17	19.63	47.11	13.6	40.4	79.37	325.94	6.25
P27	56.2	0.9	24.63	17.85	49.86	16.3	41.9	78.16	310.01	10.36
NK Perkasa	58.2	-0.7	21.54	17.78	48.74	16.3	39.8	79.72	317.89	10.31
Check means	56.9	0.3	22.36	18.68	48.23	15.4	40.7	79.59	319.21	9.44
$LSD_{0.05}$	1.8	-	6.73	2.68	2.80	1.7	3.4	3.45	89.04	2.90

DTA: days to anthesis; ASI: anthesis-silking interval (not analyzed statistically); LA: leaf angle; EL: ear length; ED: ear diameter; NER: number of kernel rows per ear; NKR: number of kernels per row; SP: shelling percentage; TGW: 1000-kernel weight (data converted to 15% moisture content); GY: grain yield; means followed by the symbol "*" in the candidate column are significantly higher (+) than the mean of all check cultivars based on LSD (least significant difference) test at the 5% level.

(20.79°), receiving a classification as upright, according to Azrai *et al*. (2025), with the leaf orientation classified as upright (<30°), semi-erect (30–45°), or drooping (>45°). A smaller leaf angle tends to produce more compact plant architecture to reduce leaf overlapping among the plants (Jafari *et al.,* 2024). Hybrid G8 had the longest ear size, while G7 showed the largest ear diameter and thousand-kernel weight. Hybrid G16 had the highest number of kernel rows per ear and shelling percentage. The most kernels per row was evident in the maize hybrid G13.

Candidate hybrid G8 produced the topmost average grain yield across the normal and high planting densities (9.73 t ha^{-1}), followed by G4 (9.13 t ha^{-1}). Both hybrids outyielded the check cultivar JHG 02 and gave grain yields comparable to those of the high-yielding check cultivars BISI 18, P27, and NK Perkasa. Several studies related to increasing maize planting density reported grain yield and its components gained influences from the genotypes used in the existing environment (Gonzalez *et al.*, 2018; Greveniotis *et al.,* 2019; Zainuddin *et al.,* 2024). This highlights the importance of the selection of genotypes with upright leaves to optimize maize productivity under the high planting density.

Table 4. Variance components, coefficients of variation, and heritability estimates of maize hybrids.

Traits	VG	VP	VE	GCV (%)	PCV (%)	H_{bs}
Days to anthesis (d)	0.52	1.06	0.73	1.28^{N}	1.82^{N}	0.49
Leaf angle (°)	44.24	50.72	8.73	24.74^{B}	26.49^{B}	0.87
Ear length (cm)	2.49	3.91	1.91	8.95^{N}	11.22^{M}	0.64
Ear diameter (mm)	6.16	7.47	1.77	5.14^{N}	5.66^{N}	0.82
Number of kernel rows per ear	23.96	26.11	2.89	13.08^{M}	13.65^{M}	0.92
Number of kernels per row	3.40	3.91	0.68	11.70^{M}	12.54^{M}	0.87
Shelling percentage (%)	8.91	10.91	2.70	3.83^{N}	4.24^{N}	0.82
1000-kernel weight (g)	3094.99	3744.42	875.33	17.20^{M}	18.92^{M}	0.83
Grain yield (t ha^{-1})	6.45	7.89	1.94	36.88^{B}	40.80^{B}	0.82

VG: genetic variance; VP: phenotypic variance; VE: environmental variance; GCV: genetic coefficient of variation; PCV: phenotypic coefficient of variation; H_{bs}: broad-sense heritability (entry-mean basis); GCV and PCV values followed by letters indicate categories: N: narrow, M: moderate; and B: broad.

Estimation of genetic parameters

The estimates of genetic parameters under normal and high planting densities are available in Table 4. The genotypic coefficient of variation (GCV) values were lower than the phenotypic coefficient of variation (PCV) for all the traits, as expected. However, the differences were small, indicating a relatively high genetic contribution to the observed variation. The influence of environmental factors appeared to be greater for ear length than for other traits. Grain yield showed the highest values in GCV (36.88%) and PCV (40.80%), being categorized as broad, and these results were greatly analogous to past observations in maize genotypes (Magar *et al.*, 2021). All traits, except days to anthesis, showed the highest heritability, suggesting that these traits had the main control of genetic factors and minimal effects from the environment (Dey *et al.,* 2019). The estimates of GCV, PCV, and heritability observed in this study were comparable with past findings recorded in maize hybrids across optimum and suboptimum abiotic environmental conditions (Zendrato *et al.*, 2025).

Phenotypic correlation

Correlation among traits under normal and high planting densities appears in Figure 2. Under the normal planting density, a significant negative correlation of grain yield was evident with the anthesis-silking interval (r = -0.56) and leaf angle (r = -0.44), while a considerable positive association resulted with shelling percentage (r = 0.51) (Figure 2a). The significant negative correlation of ASI indicates that a shorter flowering interval tends to have an association with higher grain yield, consistent with past findings of Bharathi *et al.* (2021). They reported a negative ASI correlation was desirable. Leaf angle had a significant negative correlation with grain yield, indicating that smaller leaf angles revealed an association with higher productivity, whereas larger leaf angles tended to reduce the grain yield (Zainuddin *et al.,* 2024).

In contrast, correlations under the high planting density showed that nonsignificant correlations emerged between all traits and grain yield (Figure 2b). Nevertheless, ASI expressed a significant negative correlation with the number of kernel rows per ear (r = -0.51) and 1000-kernel weight (r = -0.02), suggesting that a shorter ASI promotes improved kernel set and kernel weight under the higher planting density. These results were in contrast with those of Azrai *et al.* (2025), who reported a sizeable positive correlation between 1000-kernel weight, shelling percentage, and yield under high density.

Leaf angle showed a significant ($p < 0.05$) negative correlation with grain yield under the normal planting density, whereas under the high planting density, the correlation remained negative but was nonsignificant. Hybrid G13, identified from Table 3, exhibited the smallest leaf angle, further supporting this relationship by indicating that a narrow leaf angle contributes to a more compact plant

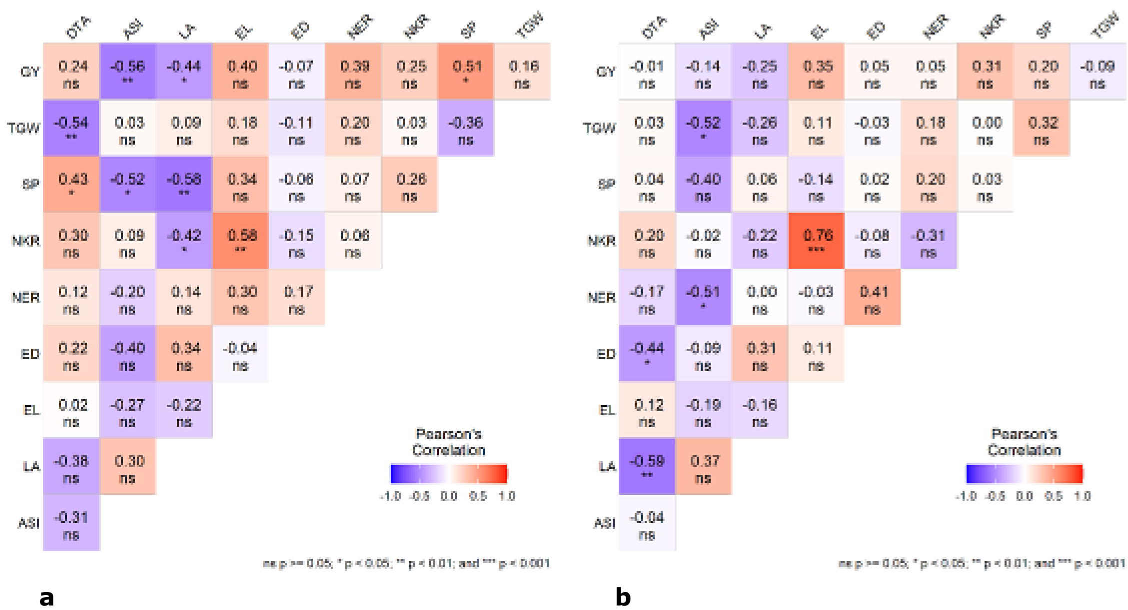

Figure 2. Pearson correlation of agronomic traits and yield components to grain yield: a) normal planting density, and b) high planting density.

architecture and improved maize productivity. Therefore, selecting maize genotypes with smaller leaf angles has the potential to improve productivity, although the correlation of leaf angle was weaker under the high planting density. Efendi *et al.* (2021) mentioned small leaf angles were desirable for achieving higher grain yield in higher plant populations. Elli *et al.* (2023) reported the correlation between leaf angle and grain yield was nonsignificant. Overall, the results suggested that while leaf angle affects grain yield, its effect depends upon the genotypes, planting density, and their interactions.

Multi-trait selection

The multi-trait genotype-ideotype distance index (MGIDI) is one of the viable approaches used for selecting simultaneously the best genotypes based on multiple important traits (Olivoto and Nardino, 2021). The ranking results showed the selected hybrids under the normal planting density were maize hybrids, viz., G20, G4, G8, G23, and G15, and in the high planting density were hybrids, i.e., G20, G23, G11, G2, and G9. Hybrid G20 had the lowest MGIDI value under both planting densities, indicating the said genotype as considerably the closest to the ideotype (Feizi *et al.,* 2025).

The selection differential (SD) reflects the variation in trait means between the original population and selected maize hybrids (Table 5). All traits with observed SD values were consistent with the expected direction of selection, indicating the selection using MGIDI occurred to be effective in accurately identifying the desired traits (Olivoto and Nardino, 2021). The strengths and weaknesses view of selected maize hybrids entailed grouping based on their contributions to each factor analysis. Their presentation is from the most contributing factors shown closer to the center point to the least contributing factor near the edge of the plot (Azrai *et al.,* 2023). The five maize hybrids selected under high planting density exhibited strengths in different factor analyses (FA), including the hybrids G20 and G23 in FA1, which were related to leaf angle, ear aspect, and grain yield. Hybrid G2 exhibited strength in FA2 relating to anthesis-silking interval and shelling percentage.

Table 5. Selection differential on selected traits based on the MGIDI index.

Factor	Traits	Sense	Goal	$\bar{x}_0$	$\bar{x}_s$	SD	% SD
Normal planting density							
FA1	Leaf angle	-	Yes	27.50	24.60	-2.93	-10.60
FA1	Ear aspect	-	Yes	3.31	2.65	-0.66	-20.00
FA1	Grain yield	+	Yes	6.21	8.14	1.93	31.10
FA1	Anthesis-silking interval	-	Yes	0.70	0.52	-0.19	-26.60
FA1	Shelling percentage	+	Yes	78.40	81.00	2.55	3.25
High planting density							
FA1	Leaf angle	-	Yes	26.70	25.20	-1.52	-5.68
FA1	Ear aspect	-	Yes	3.55	2.70	-0.85	-24.00
FA1	Grain yield	+	Yes	7.67	10.10	2.43	31.70
FA2	Anthesis-silking interval	-	Yes	0.67	0.16	-0.50	-75.80
FA2	Shelling percentage	+	Yes	77.20	80.70	3.49	4.52

$\bar{x}_0$: mean of population; $\bar{x}_s$: mean of selected hybrids; SD: selection differential; %SD: percentage of selection differential

CONCLUSIONS

Candidate hybrids G8 and G4 had relatively high average grain yields across both planting densities. Grain yield considerably increased with the higher planting density, while ear length, ear diameter, and shelling percentage decreased. Based on the MGIDI, maize hybrids G20, G4, G8, G23, and G15 (normal planting density) and G20, G23, G11, G2, and G9 (high planting density) were the best selections as potential hybrids. Leaf angle and grain yield exhibited high genotypic and phenotypic coefficients of variation and heritability estimates. Anthesis-silking interval, leaf angle, and shelling percentage proved to have a significant correlations with grain yield under normal planting density. Most of the maize check cultivars showed increased yield under the high planting density, while the check genotype JHG02 responded oppositely.

ACKNOWLEDGMENTS

The authors would like to thank the technicians at the experimental sites for helping with the experiments. This research received support from the National Research Collaboration Scheme/Riset Kolaborasi Nasional (Ri-Na) (Grant No. 555/IT3.D10/PT.01.03/P/B/2023).

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