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Agronomic Performance of IPB Maize Hybrids and Combining Ability of the Lines

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Abstract

Maize is a significant food crop consumed in numerous countries worldwide. Increasing the yield potential of maize can be achieved through the breeding of high-yielding hybrid varieties. The objectives of this study were to assess the performance of hybrid means and parent combining ability for grain yield and other agronomic traits using a line x tester mating design. The study took place at the Gunung Gede Experimental Station of IPB University, Bogor, from June to October 2022. The experiment was conducted using a randomized complete block design with a single genotype factor and three replications. Twenty-two hybrids were utilized as genetic materials, including 20 hybrid candidates and two check varieties. Six maize lines (H1, L26, Nei, P2B, and P42) were employed as line parents, while L15 and P10 were used as tester parents in the line x tester analysis. The neighbor-joining tree analysis indicated that the female parent has a significant influence on the agronomic and yield performance of the hybrids. Correlation analysis revealed that the yield is more strongly influenced by ear diameter rather than ear length, and it is more affected by the number of kernel rows than the number of kernels per row. Three selected hybrids with favorable traits were Nei x B1, L15 x L26, and L26 x P10. The parent L26 demonstrated relatively good general combining ability for yield and may be considered for future maize breeding programs.

Keywords: agronomic traits, correlation, maize breeding, yield

Introduction

Maize (*Zea mays* L.) is extensively utilized as a food source, animal feed, and raw material for various industrial products. Due to its cost-effectiveness and widespread consumption, maize is an excellent candidate for fortification, especially in regions where vitamin deficiencies pose significant public health concerns (Ranum et al., 2014). In Indonesia, the national average maize productivity in 2021 was 5.7 $t.ha^{-1}$, which is lower than the productivity in the USA (11.1 $t.ha^{-1}$) (BPS, 2021; FAO, 2023). According to Bantacut et al. (2015), the limited availability of superior maize varieties can contribute to low maize productivity. Therefore, it is crucial to develop maize varieties with higher productivity. Hybrid maize breeding programs offer a means of obtaining high-yielding maize varieties. Several traits related to yield include ear length, ear diameter, number of kernel rows, and number of kernels per row.

A single-cross hybrid variety is derived from crossing two inbred lines; this type of variety usually has superiorities over mid-parents, a phenomenon called heterosis (Hallauer et al., 2010). Hybrid varieties are more uniform than open-pollinated varieties (Acquaah, 2009). Schroeder et al. (2013) reported that the use of maize hybrids in smallholder agriculture offers potential in terms of economic development and food security, but only if the framework conditions offer a favorable environment for the adoption of the hybrids. Worku et al. (2016) stated that single-cross hybrids account for most corn acreage because of their high yield and uniformity in appearance. Soehendi and Syahri (2013) stated that some hybrid maize varieties have relatively higher yields than the composite varieties. Naturally, maize has a high level of heterozygosity (Ganal et al., 2011). Heterosis in cross-pollinated crops such as maize is usually higher than the self-pollinated crops such as rice. Hybrid maize which has a high yield and is adapted to certain environmental condition can increase in national productivity (Haryati and Sinaga, 2018). Syukur et al. (2015) suggest that prospective hybrid parental lines can be developed using various concepts, such as variety, character, or gene. The development of inbred maize lines typically involves the process of self-pollination for a minimum of seven generations, starting from a heterozygous and heterogeneous basic population (Salamah et al., 2017).

General combining ability indicates average performance of an inbred line, whereas the specific combining ability is the interaction effects of a combination of two inbred lines (Hallauer et al., 2010). The combining ability analysis is employed to identify the better combiners which can be hybridized to exploit heterosis and to select better crosses for direct use or further breeding work (Murtadha et al., 2018). The line x tester mating design is used to estimate the potential of male and female lines to produce the desired cross combination. This design is used by plant breeders to determine the appropriate crossing method in hybrid variety development programs. Tamirat et al. (2014) stated that in the maize breeding program, analysis of general combining ability (GCA), specific combining ability (SCA), and heterosis would help to identify best inbred lines for hybrid development and hybrid combinations for better specific combining ability. The objectives of this study were to estimate hybrid mean performance and parent combining ability for grain yield and other agronomic traits using line x tester mating design.

Materials and Methods

The research was conducted at the Gunung Gede Experimental Station of IPB University from June to October 2022. The experiment was arranged in a randomized complete block design with a single factor of genotype and three replications. The evaluated maize genotypes consisting of 20 test hybrids developed in IPB University, namely L26 x P13, P10 x P2B, L15 x H1, Nei x P10, L15 x Nei, P42 x P10, L15 x P10, L15 x L26, P2B x H1, Nei x B1, L22 x P2B, P10 x P13, B1 x L152, P10 x H1, L15 x P2B, L15 x P42, L22 x Nei, L26 x P10, L15 x L22, Nei x P42, and two commercial hybrid varieties as checks, namely “BISI 18” and “NK Perkasa”. The test hybrids were bred for high yield potential and had yellow grain color. All parental lines were developed by IPB University, except Nei (Nei 9008) which was obtained from the Indonesia Cereal Research Institute (ICERI). Both check varieties are yellow single cross hybrids. “BISI 18” is a widely grown variety in Indonesia produced by PT BISI International Tbk., whereas “NK Perkasa” is produced by PT Syngenta. The plot size was a single row of 5 meters, each row contained a maximum of 20 plants, and the plant spacing was 75 cm x 25 cm. The plot size was a single row of 5 meters, and the plant spacing was 75 cm x 25 cm.

Measurements were conducted on agronomic traits including plant height, ear height, stem diameter, leaf length, and leaf width, and yield-related traits including ear diameter, ear length, number of kernel rows, number of kernels per row, and yield estimates. Plant height was collected by measuring from the plants from the soil surface to the base of the male flower at the end of the vegetative phase. Stem diameter was measured using a caliper on the first node of the aerial roots, measured at the end of the flowering phase. Leaf length was measured on the first leaf above the ear leaf, measured from the node where the leaf was attached to the tip of the leaf, whereas leaf width was measured in the middle of the leaf lamina. Ear height is the height from the ground surface to the base of the main ear. Ear diameter was measured in the middle of the ear, whereas ear length from the base to the tip of the ear. The yield estimate at 15% moisture content was calculated by multiplying the average ear weight by the maximum number of plants per hectare, assuming 20% moisture content at weighing and a shelling percentage of 80%. The 15% final adjusted moisture content and 80% shelling percentage were used by Menkir et al. (2022). All plants in each plot were measured.

Quantitative data were analyzed with ANOVA (analysis of variance) followed by the t-Dunnett test at 0.05 level to compare the test hybrids with the check varieties. Repeatability on the entry-mean basis was calculated as a percentage of genotypic variance to phenotypic variance. Correlation analysis was performed to elucidate the relationship between agronomic and yield traits. The following software packages were used for data analysis: Microsoft Excel for data entry and basic calculations; SAS On-Demand for Academics (welcome.oda.sas.com) for ANOVA, t-Dunnett, and correlations; AGD-R (data.cimmyt.org/dataverse/cimmytswdvn) for combining ability analysis, PBSTAT-PPB (www.pbstat.com) for repeatability calculation, and PBSTAT-CL for cluster analysis.

Results and Discussion

Hybrid Performance

The genotype had a highly significant effect ($p<0.01$) on plant height, stem diameter, leaf length, leaf width, ear height, ear diameter, ear length, number of kernel rows, number of kernels per row, and yield, while blocks vary on plant height, stem diameter, leaf length, and ear height (Table 1). This showed that at least two genotypes were varied for a particular trait. Furthermore, the block effect was significant in plant height, stem diameter, leaf length, and ear height (data not shown). This indicated that there were differences in average trait values based on the planting location. Coefficients of variations for most traits are considerably low (less than 10%) for a field experiment, except for ear length (10.66%) and yield (24.80%), indicating that the experiment results are reliable (Table 1).

Table 1. Means of agronomic traits of the maize hybrids

No.	Hybrids	Plant height (cm)	Stem diameter (cm)	Leaf length (cm)	Leaf width (cm)	Ear height (cm)
1.	B1 x L152	175.55	2.10	84.93	9.73	98.00
2.	L15 x H1	159.18[c]	2.34[b]	89.73	9.42	110.93
3.	L15 x L22	170.42	2.28	91.08	8.87	114.53
4.	L15 x L26	175.42	2.39[ab]	80.88	9.65	102.93
5.	L15 x Nei	197.50	2.16	93.42	10.72[a]	112.27
6.	L15 x P10	173.67	2.17	97.80	9.32	105.20
7.	L15 x P2B	160.25	2.29	86.75	9.60	99.00
8.	L15 x P42	183.78	2.32[b]	85.50	9.47	117.33
9.	L22 x Nei	179.47	2.30	84.87	9.43	103.47
10.	L22 x P2B	169.32	2.23	83.18	9.42	95.87
11.	L26 x P10	162.17	2.21	88.65	9.93	91.73
12.	L26 x P13	172.15	2.26	81.10	9.73	103.33
13.	Nei x B1	191.23	2.12	88.42	10.47	102.60
14.	Nei x P10	171.92	2.20	88.72	10.12	90.47
15.	Nei x P42	187.63	1.96	88.65	10.18	112.47
16.	P10 x H1	141.38[c]	2.15	72.34	8.66	94.60
17.	P10 x P13	133.15[c]	2.25	74.92	8.95	79.93[cd]
18.	P10 x P2B	142.97[c]	2.09	92.28	9.10	83.53[a]
19.	P2B x H1	155.48[c]	2.25	84.95	9.40	89.60
20.	P42 x P10	142.02[c]	2.22	86.15	9.37	89.80
21.	"BISI 18"	197.15	2.05	85.73	9.10	115.87
22.	"NK Perkasa"	167.85	2.01	84.77	9.28	109.27
	F-test	**	**	*	*	**
	CV (%)	8.87	5.53	7.54	6.37	10.66
	R (%)	76.80	58.66	56.19	52.21	66.37

Note: * = significant at 0.05 level, ** = significant at 0.01 level, [a] = significantly higher than "BISI 18" at 5% level, [b] = significantly higher than "NK Perkasa" at 5% level, c = significantly lower than "BISI 18" at 5% level, d = significantly lower than "NK Perkasa" at 5% level, CV: coefficient of variation, R: repeatability.

Hybrid L15 x L26 had the widest stem diameter (2.39 cm), while P10 x P13 has the shortest ear height (79.93 cm). Enujeke (2013) stated that plant height among the varieties may be attributed to differences in genetic characteristics of the individual varieties, including rapid growth rates, and tallness or shortness of plants. Altitude, types of soil, and climate, affected the performance of the genotypes (Azrai et al., 2022).

The check varieties, "BISI 18" and "NK Perkasa," exhibited relatively high mean values for both agronomic and yield-related traits, as shown in Table 1 and Table 2. Nei x B1 had the highest average on ear diameter (5.77 cm) and was significantly higher than both checks while L26 x P10 had the highest mean for the number of kernel rows (18.1). The yield of all test hybrids was not significantly different with both checks, with Nei x B1 having the highest average (10.98 $t.ha^{-1}$) (Table 2). Aprilianti et al. (2016) reported that the largest ear diameter does not always guarantee that the ear will have the highest number of kernel rows. Therefore, three selected hybrids Nei x B1, L15 x L26, and L26 x P10.

Table 2. Means of yield-related traits of the maize hybrids

No.	Hybrids	Ear diameter (cm)	Ear length (cm)	Number of kernel rows	Number of kernels per row	Yield estimate ($t.ha^{-1}$)
1.	B1 x L152	5.63[a]	19.00	15.60	37.80	10.44
2.	L15 x H1	4.77	17.87	13.33[cd]	34.93	6.05
3.	L15 x L22	4.97	19.07	15.07	36.47	9.07
4.	L15 x L26	5.37	17.73	16.80	35.80	10.19
5.	L15 x Nei	5.07	19.47	14.67	40.87	7.78
6.	L15 x P10	5.00	18.53	14.07	37.20	7.71
7.	L15 x P2B	4.90	17.47	14.67	33.93	6.30
8.	L15 x P42	5.43	19.93	16.67	39.60	10.17
9.	L22 x Nei	5.10	17.80	15.07	33.13	8.45
10.	L22 x P2B	5.10	19.20	15.33	34.53	8.14
11.	L26 x P10	5.50	18.40	18.13[ab]	34.80	8.68
12.	L26 x P13	5.13	17.67	16.00	33.07	7.99
13.	Nei x B1	5.77[ab]	16.87	15.40	35.00	10.98
14.	Nei x P10	4.80	17.40	14.13	34.27	6.10
15.	Nei x P42	5.60[a]	18.47	16.87	36.20	9.78
16.	P10 x H1	4.23[cd]	15.20[c]	12.80[cd]	32.80	5.37
17.	P10 x P13	4.63	14.33[c]	13.47[cd]	32.60	7.92
18.	P10 x P2B	5.10	17.00	15.07	33.80	5.79
19.	P2B x H1	5.40	16.73	15.07	33.47	5.47
20.	P42 x P10	5.53	16.67	16.67	33.27	6.57
21.	"BISI 18"	4.90	19.67	15.33	40.00	8.23
22.	"NK Perkasa"	5.03	17.60	15.87	37.87	8.22
	F-test	**	**	**	*	*
	CV (%)	5.00	8.09	4.81	8.81	24.80
	R (%)	83.88	63.83	89.14	45.81	54.43

Note: * = significant at 0.05 level, ** = significant at 0.01 level, [a] = significantly higher than "BISI 18" at 5% level, [b] = significantly higher than "NK Perkasa" at 5% level, c = significantly lower than "BISI 18" at 5% level, d = significantly lower than "NK Perkasa" at 5% level, CV: coefficient of variation, R: repeatability.

A neighbor-joining tree of maize hybrids based on agronomic and yield-related traits is shown in Figure 1. Several pairs of hybrids having the same female parents are clustered together. For example, L15 x P10 and L15 x L22; P10 x P13 and P10 x H1; L15 x P2B and L15 x H1; L15 x P42 and L15 x L26; Nei x P42 and Nei x B1. This indicates that the female parent has a substantial effect on the agronomic and yield performance of the hybrids. The check varieties "NK Perkasa" and "BISI 18" are also clustered together, indicating that they shared some similarities in agronomic and yield traits.

According to Mohsin et al. (2014), the increment in the maize grain yield was due to increases in ear length, ear diameter, and 1000-grain weight. Yield is a quantitative trait and is influenced by various factors, including genetics and environment. Qualitative traits, on the other hand, are mostly less affected by the environment. Kernel shape and seed color are among the qualitative traits of maize grain (Nugroho et al., 2018) and grain yield is the ultimate end product of the yield-contributing components, physiological and morphological processes taking place in plants during growth and development (Tariq et al., 2014).

Correlation Among Agronomic and Yield Traits

Maize yields had highly significant ($p<0.01$) correlations with two yield components traits, ear diameter (r=0.618), and the number of kernel rows (r=0.552), and significant ($p<0.05$) correlations with the other two yield component traits, the number of kernel rows (r=0.457) and ear length (r=0.448) (Table

3). This indicates that yield is more determined by ear diameter rather than ear length and was affected more by the number of kernel rows than the number of kernels per row. With the agronomic traits, the yield had a highly significant correlation with plant height (r=0.621) and a significant correlation with ear height (r=0.457). This indicated that plant growth had a relationship with yield. However, even though the correlation between plant height and yield is positive and significant, genotypes with too tall plant stature and high ear positions are not desired as they may be more prone to lodging. A multiple-trait selection approach may be employed in breeding programs to identify such genotypes.

Plant height demonstrated a strong correlation (r=0.61) with the number of kernels per ear row, as reported by Alan et al. (2013). Additionally, Karomah et al. (2018) found a very strong and significant correlation between plant height and ear height (r=0.935). Furthermore, Ziyomo and Bernardo (2013) established a significant correlation between plant height and yield. Mohammadi et al. (2003) stated that two yield-related traits, namely the weight of 100-seeds and the number of kernels per ear had a high correlation with the total seed weight. Zarei et al. (2012) stated that there was a significant correlation between yield and ear length, 100-seed weight, and number of seeds per row. The research results of Salamah et al. (2017) showed that production characters had a significant correlation with plant height, ear height, ear length, and ear diameter. Leaves are substantial parts of plants, the larger the leaves, the higher their potential for photosynthesis. In our study, leaf length had a significant positive correlation with ear length, whereas leaf width has a strong positive correlation with ear diameter (Table 3).

Combining Ability of Inbred Lines

The estimates of general combining ability (GCA) analysis result showed that the parent Nei had a

Table 3. Correlation coefficients among agronomic and yield-related traits of the maize hybrids

	PH	SD	LL	LW	EH	ED	EL	NR	NK
SD	-0.221								
LL	0.405	-0.165							
LW	0.605**	-0.159	0.397						
EH	0.763**	-0.071	0.322	0.183					
ED	0.388	-0.133	0.324	0.551**	0.105				
EL	0.758**	-0.063	0.557**	0.313	0.717**	0.357			
NR	0.306	-0.081	0.140	0.346	0.162	0.788**	0.422		
NK	0.719**	-0.304	0.426*	0.278	0.727**	0.198	0.764**	0.209	
YE	0.621**	-0.097	0.049	0.364	0.457*	0.618**	0.448*	0.552**	0.457*

Note: * = significant at 5% level, ** = significant at 1% level, PH = plant height, SD = stem diameter, LL = leaf length, LW = leaf width, EH = ear height, ED = ear diameter, EL = ear length, NR = number of kernel rows, NK = number of kernels per row, YE = yield estimate.

Table 4. General combining ability effects of the maize inbred lines

Genotype	PH	SD	LL	LW	EH	ED	EL	NR	NK	YE
Line										
H1	-11.21	0.00	0.00	-0.47	1.14	-0.50*	0.00	-2.14**	-0.19	-1.35
L26	4.30	0.00	0.00	0.16	-0.63	0.32	0.00	2.09**	-0.01	1.81
Nei	17.65	0.00	0.00	0.67*	0.69	-0.12	0.00	-0.86	0.27	-0.30
P2B	-10.10	0.00	0.00	-0.21	-2.60	-0.06	0.00	-0.41	-0.19	-1.06
P42	-0.64	0.00	0.00	-0.15	1.40	0.36	0.00	1.32	0.13	0.91
Tester										
L15	11.01	0.06	0.00	0.11	8.86	0.00	0.61	0.00	1.34	0.70
P10	-11.01	-0.06	0.00	-0.11	-8.86	0.00	-0.61	0.00	-1.34	-0.70

Note: * = significant at 5% level, ** = significant at 1% level, PH = plant height, SD = stem diamater, LL = leaf length, LW = leaf width, EH = ear height, ED = ear diameter, EL = ear length, NR = number of kernel rows, NK = number of kernels per row, YE = yield estimate.

Table 5. Specific combining ability effects of the maize inbred lines

Line	Tester	PH	SD	LL	LW	EH	ED	EL	NR	NK	YE
H1	L15	-0.61	0.01	1.95	0.00	0.00	0.01	-0.21	0.04	-0.62	-0.01
H1	P10	-0.01	-0.01	-8.34*	0.00	0.00	-0.02	-0.87	-0.09	-0.42	0.00
L26	L15	-0.51	0.02	-3.29	0.00	0.00	0.00	-0.27	-0.14	-0.36	0.00
L26	P10	0.75	0.01	1.31	0.00	0.00	0.01	0.60	0.19	0.29	0.00
Nei	L15	0.74	-0.03	4.13	0.00	0.00	0.01	0.52	0.06	1.49	0.00
Nei	P10	0.23	0.00	1.35	0.00	0.00	-0.01	0.14	-0.08	-0.03	0.00
P2B	L15	-0.62	0.00	0.18	0.00	0.00	-0.01	-0.39	-0.05	-1.01	-0.01
P2B	P10	0.06	-0.02	3.45	0.00	0.00	0.00	-0.05	0.05	-0.03	0.00
P42	L15	1.40	0.01	-0.56	0.00	0.00	0.00	0.74	0.01	1.05	0.02
P42	P10	-1.44	0.01	-0.17	0.00	0.00	0.01	-0.20	0.01	-0.36	-0.01

Note: * = significant at 5% level, ** = significant at 1% level, PH = plant height, SD = stem diamater, LL = leaf length, LW = leaf width, EH = ear height, ED = ear diameter, EL = ear length, NR = number of kernel rows, NK = number of kernels per row, YE = yield estimate.

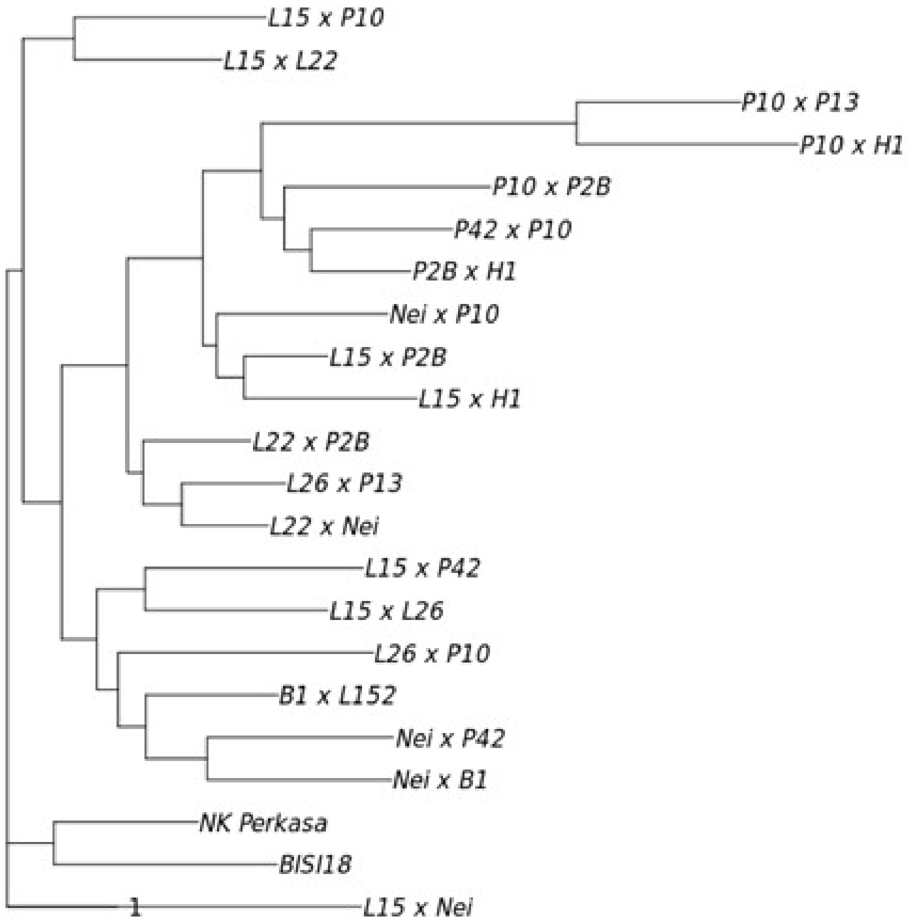

Figure 1. Neighbor-joining tree of maize hybrids based on agronomic and yield-related traits.

significant value on leaf width (0.67) while parent L26 had a significant value on the number of kernel rows (2.09) (Table 4). This indicated that parent L26 was suitable for increasing the number of kernel rows. Positive but insignificant GCA for yield was also observed on parent L26. Positive GCA values on yield-related traits observed herein are desired since they are correlated with yield. Parent with high GCA values was suitable and more effective in the development of synthetic variety as well as hybrid varieties. Good general combiners could effectively be used in future breeding programs for the development of high-yielding hybrids with desirable traits (Amiruzzaman et al., 2013).

The estimates of specific combining ability analysis results showed that none of the hybrids had significant values, except H1xP10 which showed a significant negative value on leaf length (-8.34). There results indicated that there was no significant interaction between parents in affecting the growth and yield characters (Table 5), therefore in this case, the interaction value is not meaningful for the prediction of hybrid performance. According to Murtadha et al. (2018) a negative SCA value indicated the unsuitability of both parents as a specific combiner for the trait. Furthermore, the higher variability of GCA as compared to SCA for several traits observed suggested that the hybrid prediction of such traits based on GCA may be sufficient.

Conclusion

Three selected hybrids with desirable traits were Nei x B1, L15 x L26, and L26 x P10. Among them, Nei x B1 exhibited the largest ear diameter (5.77 cm) and yield estimate (10.98 t.ha^{-1}). L15 x L26 had the largest stem diameter (2.39 cm), while L26 x P10 had the highest number of kernel rows (18.1). The yield of these selected hybrids surpassed that of the check varieties, "BISI 18" and "NK Perkasa," which yielded 8.23 and 8.22 t.ha^{-1}, respectively. The analysis using a neighbor-joining tree indicated that the female parent significantly influenced the agronomic and yield performance of the hybrids. Correlation analysis revealed that yield was more strongly determined by ear diameter rather than ear length, and it was more affected by the number of kernel rows rather than the number of kernels per row. The GCA analysis results suggested that the parent L26 demonstrated relatively good general combining ability for maize yield.

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