

Combining ability and heterotic effects of maize (*Zea mays*) lines for drought tolerance using the line \times tester method

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Abstract. Amzeri A, Santoso SB, Adiputra F, Khoiri S, Badami K, Umam AS. 2025. Combining ability and heterotic effects of maize (*Zea mays*) lines for drought tolerance using the line \times tester method. *Biodiversitas* 26: 748-760. Assembling superior varieties requires information on the combining ability and heterosis of several lines being tested to select lines that can be used as parents in assembling varieties. This research aimed to determine General Combining Ability (GCA), Specific Combining Ability (SCA), and heterosis of maize lines using the line \times tester method on dry land. The genetic material used was 40 hybrids from crossing 20 lines with UTM08.5 and UTM09.6 testers. The research used a Randomized Complete Block Design (RCBD) with 62 genotypes (20 lines, 2 testers, 40 hybrids) as treatments and was repeated three times. The research results showed that lines that have a significant negative GCA value in harvest age character and can be used as parents in assembling early maturity maize varieties are T2S-5-11, DuS-5-24, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-12, and Su-S-4-1-15. Lines with a large positive GCA value and can be used as parents for assembling maize varieties with high production character are T2S-5-11, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-15, and Su-S-4-3-16. The crosses T2S-5-11 \times UTM08.5, Su-S-4-2-4 \times UTM 08.5, and Su-S-4-1-15 \times UTM08.5 had significant negative SCA values for harvest age and significant positive SCA values for the production per hectare character so that the three cross combinations can be used as candidates for the formation of early maturity and high production hybrid maize varieties. The best crosses are ES-5-24 \times UTM09.6, T2S-5-11 \times UTM08.5, T2S-5-11 \times UTM09.6, and TS-5-20 \times UTM09.6. They have positive heterosis for production per hectare character and negative heterosis for harvest age character.

Keywords: Drought tolerance, GCA, heterosis, line \times tester crossing, SCA

INTRODUCTION

Maize is one of the important cereal plants in Indonesia and the second staple food after rice (Rozi et al. 2023; Hartanti and Yuliana 2024). In Southeast Asia, Indonesia is the largest maize-producing country, producing 17,017,000 tons ha⁻¹ in 2022 (FAO 2024). However, maize productivity in Indonesia is still low (5695.70 tons ha⁻¹) compared to the world average productivity (5872.8 tons ha⁻¹) (FAO 2021). One of the causes of low maize productivity is that the amount of maize planting area in Indonesia is dry land. The amount of dry land for maize plants in Indonesia is 24,530,076 hectares (ICALRRD 2018). Drought stress causes a decrease in maize yields in sub-tropical and tropical areas (Liu et al. 2023), where the decline in production due to drought stress is 17-60% in tropical areas (Sah et al. 2020). Drought stress can occur at every stage of maize plant growth, from germination, vegetative, and flowering to seed filling. Drought stress can disrupt the imbibition and seed germination process at the germination stage, inhibiting early plant growth (Aslam et al. 2015; Marthandan et al. 2020). In the vegetative stage, drought can cause a decrease in the rate of photosynthesis, a decrease in leaf area, and disruption of the process of cell division and enlargement (Seleiman et al. 2021; Yang et al. 2021). At the flowering

stage, drought stress can disrupt the development of female flowers (ears) and reduce the number of panicles/ears formed (Oguz et al. 2022). The selection of several maize lines for drought stress in the germination and vegetative phases produced several lines resistant to drought stress (Suhartono and Amzeri 2021). Next, a kinship test is carried out based on morphological and molecular characters to determine parents who can be used as parents in assembling superior maize varieties (Amzeri et al. 2022a).

Hybridization is a very effective method for producing maize varieties with desired characters (Lamichhane and Thapa 2022). Hybrid maize with superior characters is produced from crosses between distantly related lines and appears better than its parents. The development of hybrid maize varieties is based on using heterosis in crosses between lines (Labroo et al. 2021; Patthawaro et al. 2023). Identification of the lines used in assembling hybrid varieties is very necessary to determine potential lines that will be used as parents in assembling hybrid varieties. The analysis used to determine potential lines to be used as hybrid varieties is General Combining Ability analysis (GCA) and Specific Combining Ability analysis (SCA). Information about GCA and SCA is a prerequisite so that hybrid maize assembly can be carried out effectively and efficiently (Suyadi et al. 2021; Madhunapantula et al. 2023).

Plant breeders can use these genetic parameters (GCA and SCA) to determine additive and non-additive genes (Rachman et al. 2022; Sunny et al. 2022), making it easier to determine the right method for assembling maize varieties. GCA is the average ability of parents to join a cross with a group of other parents (Chen et al. 2019). SCA is the performance value of a hybrid in a combination of crossing the two parents (Al-Mamun et al. 2022). SCA is the performance value of a hybrid in a combination of crossing the two parents (Begna 2021).

Several methods are used to estimate the value of combining ability, including top cross, poly cross, diallel cross, line × tester, partial diallel cross, North Carolina design, and triallel cross (Fasahat et al. 2016). The method most often used is the line x tester because it is simpler in implementation and data analysis (Kahrman et al. 2016). This method involves two groups of parents being combined to produce F₁ offspring. Line x tester method can help plant breeders to estimate the General Combining Ability (GCA) and Specific Combining Ability (SCA) of the parent being tested (Modarresi et al. 2024). Furthermore, using this method can provide information about the gene's actions involved in the expression of a character so that it can be used to consider plant breeding programs (Kose 2017; Rachman et al. 2022). This research aimed to determine GCA, SCA, and heterosis of maize lines using the line × tester method on dry land.

MATERIALS AND METHODS

Plant materials and experimental design

The research was conducted from May to August 2023 in Pamekasan District, Madura, Indonesia (latitude 7°10' S, longitude 113°31' E, altitude 7 m above sea level), where the soil type is alluvial, the pH is 6.8, the average of daily temperature is 28.4, and the average of humidity is 79.85. The genetic material used was 40 hybrids, which resulted from crossing 20 lines with the UTM08.5 and UTM09.6 testers (Table 1). The research used a Randomized Complete Block Design (RCBD) with 62 genotypes (20 lines, 2 testers, 40 hybrids) as treatments and was repeated three times so that there were 186 experimental units. Each experimental unit consisted of 50 plants. Each genotype was planted in a plot measuring 1 × 5 m with a 70 × 20 cm spacing. Fertilization is carried out in three stages, namely when the plants are 7 Days After Planting (DAP) (200 kg ha⁻¹ SP-36, 100 kg ha⁻¹ Urea, and 50 kg ha⁻¹ KCl), 25 DAP (100 kg ha⁻¹ Urea and 50 kg ha⁻¹ KCl, and 40 DAP (100 kg ha⁻¹ Urea and 50 kg ha⁻¹ KCl). Drought stress in this study followed the CIMMYT method (Weber et al. 2012) namely drought stress was carried out when the plants were 40 DAP until harvest but provided irrigation with field capacity from 0 DAP to 40 DAP with intervals of every 10 days.

Data collection and analysis

Observations were made on 20 sample plants in each experimental unit. The characters observed were plant height, days to 50% tasselling, harvest age, ear height, ear length, ear diameter, kernel weight per plant, 1000-kernel weight, and production per hectare (Akfindarwan et al. 2023). Maize plants are harvested when the maize ears are physiologically mature, which is characterized by the husks being dry or brownish in color, the seeds having hardened, and a black layer of at least 50% in each row of seeds. At that time, the moisture content of the seeds usually reaches less than 30%. Observations of corn grain yield were carried out on all plant samples for each experimental unit and converted into maize grain yield per hectare at a water content of 15% using the following formula:

$$Y = \frac{10.000}{HA} \times \frac{100 - MC}{100 - 15} \times GW$$

Where:

Y : Grain yield (kg h⁻¹)

HA : Harvested area per plot (m²)

MC : Moisture content at harvest time (%)

GW : Harvested grain weight per plot (kg)

Table 1. 22 lines used in the line x tester cross

Genotypes	Origins
TS-5-20	Madura Island, Indonesia
T2S-5-11	Madura Island, Indonesia
DuS-5-02	Madura Island, Indonesia
ES-5-24	Madura Island, Indonesia
MS-5-06	Madura Island, Indonesia
CS-5-43	Madura Island, Indonesia
DS-5-3-1	Madura Island, Indonesia
GS-4-2-1	Madura Island, Indonesia
An-S-4-1-5	ICERI, Indonesia
La-S-4-2-4	ICERI, Indonesia
Bi-S-4-1-10	ICERI, Indonesia
Su-S-4-2-4	ICERI, Indonesia
Su-S-4-1-12	ICERI, Indonesia
Su-S-4-1-15	ICERI, Indonesia
Su-S-4-3-16	ICERI, Indonesia
Lm-S-4-2-12	ICERI, Indonesia
Lm-S-4-2-2	ICERI, Indonesia
Ba-S-4-3-1	Probolinggo, East Java, Indonesia
Ba-S-4-2-2	Probolinggo, East Java, Indonesia
PI-S-5-2	Kediri, East Java, Indonesia
UTM08.5	S7 line extracted from a population of material resistant to drought and Downey mildew disease (derived from a Madura's local cultivar)
UTM09.6	S7 line extracted from a population of drought-resistant material (derived from a Madura local cultivar)

Analysis of variance was carried out to determine the effect of female parents (line), male parents (tester), and the interaction of female and male parents (line \times tester). Analysis of variance used STAR 2.0.1 software and a normality test was carried out before calculating the analysis of variance. If there is a difference in the influence of genotype in the factorial analysis of combining ability, then continue with the GCA and SCA analysis. The effects of line GCA, tester GCA, and SCA were estimated using the Singh and Chudary method (Singh and Chaudary 1979). The heterosis value is estimated based on the Mid-Parent Heterosis (MPH) and Best-Parent Heterosis (BPH) values using the Hallauer and Carena method (Hallauer et al. 2010). Pearson correlation coefficient analysis based on Walpole (Walpole 1982) to determine the close relationship between the observed characters. Line \times tester analysis uses RStudio version 3.0.1 software and Pearson correlation analysis uses STAR 2.0.1 software.

RESULTS AND DISCUSSION

Analysis of variance shows that the line has an effect on all the observed characters, while the tester affects kernel weight per plant and 1000-kernel weight (Table 2). The interaction between line \times tester significantly affected all observed characters except plant height. Characters with real interaction between line \times tester indicate that each line performs differently when crossed with each tester (Priyanto et al. 2019). This event may be caused by the greater influence of non-additive genes than additive genes on the inheritance of these characters (Azrai et al. 2014; Andayani et al. 2018). In addition, characters that do not have significant interactions between line \times testers may be due to additive genes playing a greater role in their inheritance (El-Gammal et al. 2019; Kargbo et al. 2019).

Average character of lines, testers, and hybrids

The results of measuring all characters in 62 genotypes (20 lines, 2 testers and 40 hybrids) are shown in Table 3. The character of harvest age and production per hectare is of concern in this research. The development of hybrid

maize varieties in dry land is characterized by early maturity and high production (Amzeri et al. 2023). Hybrid maize has a higher average value than its two parents (line and tester) for ear height, 1000-weight kernels, and production per hectare. Furthermore, the hybrid maize genotype did not exceed its two parents in terms of plant height, days to 50% tasselling, harvest age, ear diameter, and kernel weight per plant. These results show that combining lines and testers can produce offspring (hybrids) with early maturity and high production character.

The hybrid maize with the highest production per hectare is Su-S-4-1-12 \times UTM08.5 (No. 13) which exceeds both parents. A cross between two distantly related maize parents can produce a hybrid with higher yields than both parents through a phenomenon known as heterosis (Würschum et al. 2023). Fourteen hybrid maize which have production character above 5 tons per hectare, namely TS-5-20 \times UTM08.5 (No. 1), T2S-5-11 \times UTM08.5 (No.2), Su-S-4-2-4 \times UTM 08.5 (No. 12), Su-S-4-1-12 \times UTM08.5 (No. 13), Su-S-4-1-15 \times UTM08.5 (No. 14), Su-S-4-3-16 \times UTM08.5 (No. 15), Ba-S-4-3- 1 \times UTM08.5 (No. 18), Ba-S-4-2-2 \times UTM08.5 (No. 19), TS-5-20 \times UTM09.6 (No. 21), T2S-5-11 \times UTM09.6 (No. 22), ES-5-24 \times UTM09.6 (No. 24), Su-S-4-2-4 \times UTM 09.6 (No. 32), Su-S-4-1-12 \times UTM09.6 (No. 33), and Su-S-4-3-16 \times UTM09.6 (No. 35). The fourteen hybrid maize varieties can be used as high-production hybrids. Furthermore, all maize hybrids have a harvest age of under 95 days, except for La-S-4-2-4 \times UTM09.6 (No. 30), which is 100.37 days, so almost all hybrids can be used to produce maize varieties with early maturity character.

General combining ability

Twenty lines tested had different GCA values for each observed character. The number of lines that have positive GCA values for plant height characters is 11 lines, 8 lines at days to tasselling, 11 lines at harvest age, 12 lines at ear height, 13 lines at ear diameter, 1s at kernel weight per plant, 9 lines at 1000-kernel weight, and 9 lines at production per hectare (Table 4). Negative and significant GCA values are found in days to 50% tasselling, harvest age, ear height, kernel weight per plant, and 1000-kernel weight.

Table 2. Analysis of variance based on mean squares and genetic components through line by tester analysis on drought stress-tolerant maize

Source	d.f.	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
Replications	2	144.03**	3.15**	0.49*	45.83**	0.01	0.04	175.68**	4405.17**	0.07*
Genotypes	61	1312.41**	112.59**	508.37**	114.61**	12.98**	2.03**	753.59**	2022.90**	5.95**
Parents	21	1294.83**	174.90**	736.50**	180.70**	23.38**	2.44**	728.91**	1590.57**	8.39**
Parent vs. Crosses	1	39.09**	68.71**	3270.44**	11.55**	17.12**	5.99**	3119.19**	865.11**	4.79**
Crosses	39	1354.53**	80.16**	314.71**	81.67**	7.28**	1.71**	706.22**	2285.39**	4.67**
Lines	19	2780.35**	137.27**	528.32**	142.19**	13.71**	2.71**	1273.11**	3585.55**	8.10**
Tester	1	0.00	78.39	267.04	9.36	3.72	6.88**	1367.82**	2618.09	0.74
Lines \times Testers	19	0.00	23.14**	103.61**	24.96**	1.03**	0.44**	104.51**	969.72**	1.45**
Error	122	1.45	0.13	0.12	0.57	0.04	0.01	14.52	103.99	0.02

Note: PH: Plant Height (cm); DT: Days to 50% Tasselling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare; d.f: Degrees of freedom; ns: $p \geq 0.05$; * $p < 0.05$; ** $p < 0.01$

Table 3. Mean performance of F1 hybrids for various characters in maize

Hybrids	Parameters								
	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
TS-5-20 × UTM08.5	190.97	47.33	85.38	94.11	15.25	5.25	81.74	202.11	5.63
T2S-5-11 × UTM08.5	191.43	45.11	85.26	89.22	15.21	5.19	82.50	211.33	6.14
DuS-5-24 × UTM08.5	168.75	40.33	85.33	81.22	11.22	2.85	54.13	136.27	2.75
ES-5-24 × UTM08.5	193.92	45.22	86.26	90.33	14.23	5.19	79.44	215.66	4.24
MS-5-06 × UTM08.5	165.58	41.11	83.29	80.22	11.52	3.79	32.26	187.26	3.42
CS-5-43 × UTM08.5	158.73	35.22	72.53	69.22	13.36	3.49	29.19	189.55	2.36
DS-5-3-1 × UTM08.5	194.21	49.22	87.65	99.56	15.09	5.36	81.49	281.03	4.77
GS-4-2-1 × UTM08.5	171.35	41.45	84.51	81.44	13.06	3.56	53.03	190.95	2.83
An-S-4-1-5 × UTM08.5	166.53	50.33	82.50	100.33	14.45	4.07	61.67	186.44	4.18
La-S-4-2-4 × UTM08.5	197.35	49.45	89.77	98.67	15.43	4.40	60.77	184.52	4.05
Bi-S-4-1-10 × UTM08.5	192.03	53.11	83.97	105.11	14.67	4.68	53.47	183.06	4.11
Su-S-4-2-4 × UTM 08.5	196.12	55.56	91.82	110.22	17.14	5.53	80.65	214.23	6.83
Su-S-4-1-12 × UTM08.5	199.05	54.22	92.29	106.67	16.66	5.57	84.09	217.33	7.44
Su-S-4-1-15 × UTM08.5	197.35	56.22	89.89	110.22	17.04	5.55	82.91	220.92	6.95
Su-S-4-3-16 × UTM08.5	193.66	55.56	88.39	109.33	17.64	5.54	81.79	277.66	6.33
Lm-S-4-2-12 × UTM08.5	190.36	49.67	83.60	99.33	15.36	4.52	67.15	187.70	4.29
Lm-S-4-2-2 × UTM08.5	189.23	49.67	84.28	94.11	15.52	4.65	71.44	189.63	3.89
Ba-S-4-3-1 × UTM08.5	194.25	49.44	90.66	98.33	14.69	5.24	79.22	219.91	5.46
Ba-S-4-2-2 × UTM08.5	200.08	49.78	92.45	99.11	14.52	5.46	78.60	215.49	5.33
Pl-S-5-2 × UTM08.5	192.42	50.55	82.54	100.33	14.29	4.04	64.85	185.30	3.87
TS-5-20 × UTM09.6	173.78	45.67	85.70	91.11	15.14	4.95	75.49	215.66	5.37
T2S-5-11 × UTM09.6	175.51	44.44	85.92	88.33	14.63	5.06	73.53	219.17	5.74
DuS-5-24 × UTM09.6	159.37	40.55	86.79	80.33	11.23	2.76	52.47	133.56	3.30
ES-5-24 × UTM09.6	180.29	45.22	88.25	88.22	14.77	4.95	73.73	232.29	5.22
MS-5-06 × UTM09.6	155.63	45.33	84.53	91.33	10.96	3.48	30.77	191.04	2.48
CS-5-43 × UTM09.6	138.60	35.44	73.93	70.33	13.07	3.54	26.14	194.11	2.80
DS-5-3-1 × UTM09.6	160.78	42.33	82.76	84.33	13.21	3.74	55.39	225.57	3.60
GS-4-2-1 × UTM09.6	167.07	41.89	83.14	84.00	13.10	3.43	54.59	187.98	3.03
An-S-4-1-5 × UTM09.6	162.17	50.56	71.63	100.11	14.28	4.04	58.51	186.70	4.96
La-S-4-2-4 × UTM089.6	195.75	47.67	100.37	95.33	14.80	4.46	62.61	188.72	5.00
Bi-S-4-1-10 × UTM09.6	182.45	53.44	85.41	104.11	14.68	4.33	57.41	181.70	4.98
Su-S-4-2-4 × UTM 09.6	188.22	50.67	87.10	101.11	15.81	4.62	63.04	185.08	5.81
Su-S-4-1-12 × UTM09.6	190.44	52.67	89.32	104.22	15.85	4.64	65.41	185.73	5.08
Su-S-4-1-15 × UTM09.6	191.96	51.89	86.73	105.33	15.55	4.67	64.77	186.73	5.00
Su-S-4-3-16 × UTM09.6	193.40	54.67	85.91	109.33	15.52	4.73	64.66	192.22	5.86
Lm-S-4-2-12 × UTM09.6	187.40	48.56	84.18	94.22	15.67	4.53	67.25	187.31	4.79
Lm-S-4-2-2 × UTM09.6	185.42	48.56	83.94	97.33	15.93	4.46	64.62	187.39	4.94
Ba-S-4-3-1 × UTM09.6	193.92	48.56	91.28	97.11	15.45	4.05	74.83	219.53	4.89
Ba-S-4-2-2 × UTM09.6	192.41	48.33	90.47	95.33	15.28	3.85	78.26	220.81	4.86
Pl-S-5-2 × UTM09.6	184.94	48.22	83.85	96.33	14.35	4.06	61.85	188.21	4.03
Line mean	173.54	46.24	85.23	84.87	13.96	4.01	55.07	196.66	4.34
Tester mean	184.08	49.72	86.51	98.50	14.45	4.83	66.29	185.40	4.19
Hybrid mean	182.57	47.83	85.84	94.88	14.64	4.46	64.64	200.15	4.67
CV (%)	0.69	0.77	0.88	0.38	1.31	2.53	6.19	5.14	2.80
HSD (0.05)	4.14	1.25	2.59	1.19	0.65	0.38	13.09	35.03	0.48

Note: PH: Plant Height (cm); DT: Days to 50% Tasselling (days); HA: Harvest Age (days); EH: Ear Height (cm); EL: Ear Length (cm); ED: Ear Diameter (cm); KWP: Kernel Weight per Plant (g); 1000KW: 1000-Kernel Weight (g); PPH: Production Per Hectare (tons); CV: Coefficient of Variation; HSD: Tukey's Honest Significant Difference

The GCA values were negative and significant for the character of days to 50% tasselling, harvest age in 5 lines, ear height in 3 lines, kernel weight per plant in 4 lines, and 1000-kernel weight in 10 lines. A negative GCA value indicates that the average character of a line is smaller than the total average of all crosses (Abed Hassan et al. 2020; Al-Mamun et al. 2022). A negative GCA value in a character is caused by a negative over-dominant gene (Boeven et al. 2020). A negative over-dominant gene action causes a character in the heterozygous state to have a lower value than the homozygous one (Priyanto et al. 2019).

The direction for developing maize plant varieties on dry land is the development of hybrid maize varieties that are early maturity and have high yields. Early maturity hybrid maize varieties can be assembled from lines with negative GCA values for harvest age character. The lines with early maturity characters with significant negative GCA values are T2S-5-11, DuS-5-24, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-12, and Su-S-4-1-15. Furthermore, high-yielding hybrid maize varieties can be assembled from lines with positive GCA values at production per hectare character. In Table 4, there are no lines that have production

per hectare characteristics with a significantly positive GCA value, but there are lines that have quite large positive GCA values, namely T2S-5-11, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-15, and Su-S-4-3-16. This positive value indicates that the line affects adding value to the production characteristics per hectare (Tabu et al. 2023; Engida et al. 2024). Differences in the genetic background of the lines influence the effects of combining ability (Billah et al. 2025).

The UTM09.06 tester has a negative GCA value for the harvest age character. It can be used as a parent to obtain maize plant varieties that have an early maturity. The UTM08.5 tester has a positive and significant GCA value for the 1000-kernel weight character, so it can be used as a parent to improve this character. The research results of Fikri et al. (2023) and Sudika et al. (2023) show that there is a significant positive correlation between the 1000-kernel weight and production per hectare so increasing the 1000-kernel weight will have an impact on increasing production per hectare.

Specific combining ability

Specific combining ability is the ability of pure lines to combine in a specific cross. A positive specific combining ability value indicates that the cross combination has a higher value than the parents used, while a negative SCA value indicates the opposite (Gaballah et al. 2022; Chikh-

Rouhou et al. 2024). Almost all the characters observed had significant SCA values except for plant height (Table 5). Harvest age and production per hectare must be considered to produce superior maize resistant to drought stress. Superior maize, which has early maturity, will avoid drought conditions on land with short rainy months (Abadi and Sugiharto 2019; Nivethitha et al. 2023). Furthermore, superior maize with a high production character is expected to solve the problem of low maize production in dry land.

Regarding harvest age characters, 18 cross combinations have significant positive SCA, and 18 cross combinations have significant negative SCA values. Hybrid maize with early maturity characters was obtained from cross combinations with significant negative SCA values for harvest age characters (Chiuta and Mutengwa 2020), so 18 cross combinations could be used as candidates for hybrid maize with early maturity characters. In production per hectare character, there are 18 cross combinations with significant positive SCA values, which can be used to make hybrid maize with high production. The combination of crosses for harvest age characters with significant negative SCA values is not always followed by production per hectare characters with significant positive SCA values. In addition, the character of production per hectare with a high positive SCA value is not always accompanied by high production per hectare (>5 tons per hectare).

Table 4. General Combining Ability (GCA) values of lines and testers for all observed maize characters

Parents	Parameters								
	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
Lines									
TS-5-20	-19.17	-1.61	-3.21	-0.30	0.56	0.64	13.97*	8.79**	0.84
T2S-5-11	-16.91	-5.05	-9.1**	-0.25	0.28	0.67	13.37*	15.11**	1.28
DuS-5-24	-15.57	-9.66**	-20.15**	0.22	-3.42	-1.65	-11.94	-65.23**	-1.64
ES-5-24	-14.46	-2.50	-4.38	1.42	-0.14	0.61	11.94	23.83**	0.07
MS-5-06	-28.43	2.06	4.63	-1.93	-3.40	-0.82	-33.18**	-11.00**	-1.71
CS-5-43	-53.23	6.5*	12.79**	-12.61**	-1.42	-0.94	-36.98**	-8.32**	-2.08
DS-5-3-1	-16.44	7.39**	13.57**	-0.63	-0.49	0.09	3.79	53.16**	-0.48
GS-4-2-1	-11.20	4.78	9.46**	-2.01	-1.56	-0.96	-10.83	-10.68**	-1.73
An-S-4-1-5	-13.85	1.72	1.35	-8.78**	-0.28	-0.41	-4.55	-13.58**	-0.10
La-S-4-2-4	28.37	2.34	4.85	9.23**	0.48	-0.03	-2.95	-13.52**	-0.14
Bi-S-4-1-10	13.58	-2.78	-5.15	-1.15	0.03	0.05	-9.20	-17.77**	-0.12
Su-S-4-2-4	13.22	-4.94	-10.6**	3.62	1.83	0.62	7.20	-0.49	1.66
Su-S-4-1-12	17.86	-7.44**	-14.04**	4.97	1.61	0.65	10.11	1.38	1.60
Su-S-4-1-15	18.88	-5.72	-10.71**	2.47	1.65	0.65	9.20	3.68	1.31
Su-S-4-3-16	16.85	1.28	2.85	1.31	1.94	0.67	8.54	34.79**	1.43
Lm-S-4-2-12	15.89	4.22	7.74**	-1.95	0.88	0.07	2.56	-12.64**	-0.12
Lm-S-4-2-2	18.86	4.45	9.9**	-1.73	1.09	0.10	3.39	-11.64**	-0.25
Ba-S-4-3-1	10.12	3.78	6.9*	5.13	0.43	0.19	12.38*	19.57**	0.51
Ba-S-4-2-2	16.66	0.73	2.35	5.62	0.26	0.20	13.79**	18.00**	0.43
Pl-S-5-2	18.97	0.45	0.96	-2.64	-0.32	-0.41	-1.29	-13.39**	-0.72
S.E. (gi) line	0.49	0.15	0.14	0.31	0.08	0.04	1.56	4.16*	0.05
S.E. (gi-gj) line	0.70	0.21	0.20	0.44	0.11	0.06	2.20	5.89*	0.07
Testers									
UTM08.5	0.00	0.81	1.49	0.28	0.18	0.24	3.38	4.67**	0.08
UTM09.6	0.00	-0.81	-1.49	-0.28	-0.18	-0.24	-3.38	-4.67**	-0.08
S.E. (gi) tester	0.16	0.05	0.04	0.10	0.02	0.01	0.49	1.32	0.02
S.E. (gi-gj) tester	0.22	0.07	0.06	0.14	0.03	0.02	0.70	1.86	0.02

Note: PH: Plant Height; DT: Days to 50% Tasseling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare; S.E.: Standard Error

Table 5. Specific Combining Ability (SCA) values of lines and testers for all observed maize characters

F1 hybrids	Parameters								
	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
TS-5-20 × UTM08.5	0.00	-0.44	0.95**	0.30*	-0.12	-0.09	-0.25	11.45*	0.05
T2S-5-11 × UTM08.5	0.00	-0.61	-6.05**	-0.35*	0.12	-0.18*	1.11	8.59*	0.12*
DuS-5-24 × UTM08.5	0.00	-1.01*	-3.27**	-1.81**	-0.18*	-0.19**	-2.55	-3.32	-0.36**
ES-5-24 × UTM08.5	0.00	-1.27**	7.57**	3.08**	-0.44**	-0.12*	-0.52	-12.99*	-0.36**
MS-5-06 × UTM08.5	0.00	-0.90*	-0.66**	-0.37*	0.10	-0.09	-2.63	-6.56	0.39**
CS-5-43 × UTM08.5	0.00	-0.98*	-4.05**	-2.03**	-0.03	-0.27**	-1.85	-6.95	-0.30**
DS-5-3-1 × UTM08.5	0.00	2.17**	-3.27**	-1.81**	0.76**	0.57**	9.68**	23.06**	0.51**
GS-4-2-1 × UTM08.5	0.00	0.40	3.51**	2.13**	-0.20*	-0.17	-4.16*	-3.19	-0.18*
An-S-4-1-5 × UTM08.5	0.00	5.16**	-3.60**	-0.70*	-0.09	-0.22**	-1.80	-4.80	0.47**
La-S-4-2-4 × UTM08.5	0.00	-5.58**	-2.10**	-1.20**	0.14	-0.27**	-4.30*	-6.77	-0.55**
Bi-S-4-1-10 × UTM08.5	0.00	-1.00*	0.10	-0.20	-0.18*	-0.06	-5.35*	-3.99	-0.51**
Su-S-4-2-4 × UTM 08.5	0.00	2.08**	-5.44**	-3.14**	0.49**	0.21**	5.43*	9.91*	0.43**
Su-S-4-1-12 × UTM08.5	0.00	1.21*	9.01**	4.14**	0.23*	0.23**	5.96*	11.13*	0.90**
Su-S-4-1-15 × UTM08.5	0.00	1.30**	-1.33**	-0.59*	0.57**	0.20**	5.69*	12.42*	0.90**
Su-S-4-3-16 × UTM08.5	0.00	0.96*	0.90**	0.64*	0.88**	-0.17*	5.19*	38.05**	0.16*
Lm-S-4-2-12 × UTM08.5	0.00	-0.57	0.01	0.58*	-0.33**	-0.24**	-3.43*	-4.47	-0.33**
Lm-S-4-2-2 × UTM08.5	0.00	-0.11	-2.05**	-0.42*	-0.38**	-0.14*	0.03	-3.55	-0.60*
Ba-S-4-3-1 × UTM08.5	0.00	-0.59	6.06**	2.25**	-0.56**	0.37**	-1.18	-4.48	0.21**
Ba-S-4-2-2 × UTM08.5	0.00	0.71*	-1.38**	-0.81*	-0.56**	0.56**	-3.21*	-7.33	0.16*
Pl-S-5-2 × UTM08.5	0.00	-0.93*	-1.99**	-0.75*	-0.21*	-0.25**	-1.88	-6.13	-0.15*
TS-5-20 × UTM09.6	0.00	0.44	-0.95**	-0.30*	0.12	0.09	-0.25	-11.45*	-0.05
T2S-5-11 × UTM09.6	0.00	0.61	6.05**	0.35*	-0.12	0.18*	-1.11	-8.59*	-0.12*
DuS-5-24 × UTM09.6	0.00	1.01*	-3.27**	1.81**	0.18*	0.19**	2.55	3.32	0.36*
ES-5-24 × UTM09.6	0.00	1.27**	-7.57**	3.08**	0.44**	0.12*	0.52	12.99*	0.36*
MS-5-06 × UTM09.6	0.00	0.90*	0.66**	0.37*	-0.10	0.09	2.63	6.56	-0.39*
CS-5-43 × UTM09.6	0.00	0.98*	4.05**	2.03**	0.03	0.27**	1.85	6.95	0.30**
DS-5-3-1 × UTM09.6	0.00	-2.17**	3.27**	1.81**	-0.76**	-0.57**	-9.68**	-23.06**	-0.51**
GS-4-2-1 × UTM09.6	0.00	-0.40	3.51**	-2.13**	0.20*	0.17*	4.16*	3.19	0.18*
An-S-4-1-5 × UTM09.6	0.00	-5.16**	3.60**	0.70*	0.09	0.22**	1.80	4.80	-0.47**
La-S-4-2-4 × UTM089.6	0.00	5.58**	2.10**	1.20**	-0.14	0.27**	4.30*	6.77	0.55**
Bi-S-4-1-10 × UTM09.6	0.00	1.00*	-0.10	0.20	0.18*	0.06	5.35*	3.99	0.51**
Su-S-4-2-4 × UTM 09.6	0.00	-2.08**	5.44**	3.14**	-0.49**	-0.21**	-5.43*	-9.91*	-0.43**
Su-S-4-1-12 × UTM09.6	0.00	-1.21*	-9.01**	-4.14**	-0.23*	-0.23**	-5.96*	-11.13*	-0.90**
Su-S-4-1-15 × UTM09.6	0.00	-1.30**	1.33**	0.59*	-0.57**	-0.20**	-5.69*	-12.42*	-0.90**
Su-S-4-3-16 × UTM09.6	0.00	-0.96*	-0.90**	-0.64*	-0.88**	0.17*	-5.19*	-38.05**	-0.16*
Lm-S-4-2-12 × UTM09.6	0.00	0.57	-0.01	-0.58*	0.33**	0.24**	3.43*	4.47	0.33**
Lm-S-4-2-2 × UTM09.6	0.00	0.11	2.05**	0.42*	0.38**	0.14*	-0.03	3.55	-0.60**
Ba-S-4-3-1 × UTM09.6	0.00	0.59	-6.06**	-2.25**	0.56**	-0.37**	1.18	4.48	-0.21**
Ba-S-4-2-2 × UTM09.6	0.00	-0.71*	1.38**	0.81*	0.56**	-0.56**	3.21*	7.33	-0.16*
Pl-S-5-2 × UTM09.6	0.00	0.93*	1.99**	0.75*	0.21*	0.25**	1.88	6.13	0.15*
S.E. (sij)	0.70	0.43	0.20	0.21	0.11	0.06	2.20	5.89	0.07
S.E. (sij-skl) tester	0.98	0.62	0.28	0.29	0.15	0.09	3.11	8.33	0.10

Note: PH: Plant Height; DT: Days to 50% Tasseling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare; S.E.: Standard Error

For this reason, determining superior hybrid maize candidates with early maturity and high production character must consider the SCA value of the significant negative harvest age character followed by the high production character (>5 tons per hectare) with a significant positive SCA value. The crosses T2S-5-11 × UTM08.5, Su-S-4-2-4 × UTM 08.5, and Su-S-4-1-15 × UTM08.5 have significant negative SCA values for harvest age and significant positive SCA values for production per hectare, so the three cross combinations can be used as candidates for the formation of early maturity and high production hybrid maize varieties.

Line pairs with a significant positive SCA effect do not always result from line pairs with a significant positive GCA effect. In production per hectare character, the cross between DuS-5-24 × UTM09.6 has a negative GCA value (-1.64 and -0.08), but has a significant positive SCA value (0.36). In addition, significant positive SCA values can be obtained from parents with positive and negative GCA values. In production per hectare character, the cross MS-5-06 × UTM08.5 has a significant positive SCA value which comes from parents with a negative GCA value (MS-5-06 = -1.71) and a positive GCA value (UTM08.5 = 0.08). This phenomenon is thought to mean that this character is complex and controlled by many genes that are additive, dominant, and epistasis (Al-Mamun et al. 2023; Viana 2023).

Heterosis

Heterosis is a hybrid event (F₁) that results from crossing two different parents that have superior characters compared to the two parents (Rehman et al. 2021; Hanafiah et al. 2023). Heterosis provides information about the increase and decrease in Mid-Parent Heterosis (MPH) and Best-Parent Heterosis (BPH) in F₁ plants. MPH and BPH values are influenced by the overdominant action genes in both parents, which are inherited from their offspring for quantitative characters (Al-Mamun et al. 2022; Sang et al. 2022). The heterosis phenomenon in F₁ plants is thought to be caused by the two parents having different genetic backgrounds or being distantly related (Wakchaure et al. 2015; Wu et al. 2021).

Estimation of Mid-Parent Heterosis (MPH) in 40 hybrid plants (F₁) for plant height character (-4.76% to 2.56%, -0.03% on average), days to 50% tasselling (-14.55% to 8.46%, -0.44% on average), harvest age (-13.47% to 16.14%, 3.43% on average), ear height (-4.76% to 2.59%, -0.03% on average), ear length (-4.22% to 15.14%, 3.16% on average), ear diameter (-16.43% to 34.36%, 1.06% on average), kernel weight per plant (-35.41% to 50.93%, 6.02% on average), 1000-kernel weight (-10.17% to 39.48%, on average 4.48%), and production per hectare (-27.15% to 66.78%, on average 10.13%) (Figure 1; Table 6). Estimation of best-parent heterosis (BPH) in 40 hybrid plants (F₁) for plant height character (-18.14% to 2.50%, -3.02% on average), days to 50% tasselling (-30.47% to 12.08%, -37.8% on average), harvest age (-30.54% to 12.33%, -3.68% on average), ear height (-18.14% to 11.36%, -3.02% on average), ear length (-23.56% to 11.36%, -1.58% on average), ear diameter (-44.08% to 8.73%, -9.99% on average), kernel weight per plant (-58.51% to 30.04%, -4.19% on average), 1000-kernel weight (-27.74% to 31.17%, 0.72% on average), production per hectare (-45.78% to 43.33%, -5.68% on average) (Figure 1; Table 7).

Early maturity and high production are the character that are used as the focus for developing hybrid maize on dry land. In the harvest age character, the heterosis value, which indicates an early maturity, is a negative heterosis value. The negative MPH and BPH values (ranked 1 to 3 lowest values) are CS-5-43 × UTM08.5, CS-5-43 ×

UTM09.6, and DuS-5-24 × UTM08.5, where the harvest age of all three crosses were under 90 days (Table 3). According to Azrai (2013) the harvest age of maize is divided into three groups, namely (1) short or early maturity (75-95 days), (2) medium maturity (95-120 days), and (3) long maturity (more of 120 days). The lowest MPH value in the three crosses was -13.47%, while the lowest BPH value among the three crosses was -30.54%.

In the character of production per hectare, the heterosis value, which indicates high production, is the positive heterosis value. The positive MPH values (ranked 1 to 3 highest) are ES-5-24 × UTM09.6, T2S-5-11 × UTM08.5, and T2S-5-11 × UTM09.6. Furthermore, the BPH values that are positive (ranked 1 to 3 highest) are T2S-5-11 × UTM09.6, T2S-5-11 × UTM08.5, and TS-5-20 × UTM09.6. The highest MPH value is 66.78%, while the highest BPH value is 43.33%. Production per hectare of this cross is above 5.00 tons per hectare under drought conditions (Table 3).

The relationship between hybrid performance and Mid-Parent (MP)

The coefficients of simple linear correlation between hybrid performance and MP were significant for plant height, ear height, and ear diameter. Kernel weight per plant, 1000-kernel weight, and production per hectare. The coefficients of simple linear correlation between hybrid performance and MP were non-significant for the character of days to 50% tasselling, harvest age, and ear length (Figure 2). The character with a correlation value greater than 0.80 is a 1000-kernel weight. A correlation value of more than 0.80 (very strong correlation) indicates that the MP value can be used to predict hybrid performance on the 1000-weight kernel. However, it is less effective for predicting other characters because it has a correlation coefficient value of less than 0.80. Several studies have identified five main contributing factors to the effectiveness of mid-parent values in predicting hybrid character: the type of plant used as a parent, agronomic characteristics, environmental conditions, selection of parents, and MPH and BPH values (Wiguna and Sumpena 2015; Krisnawati and Adie 2022).

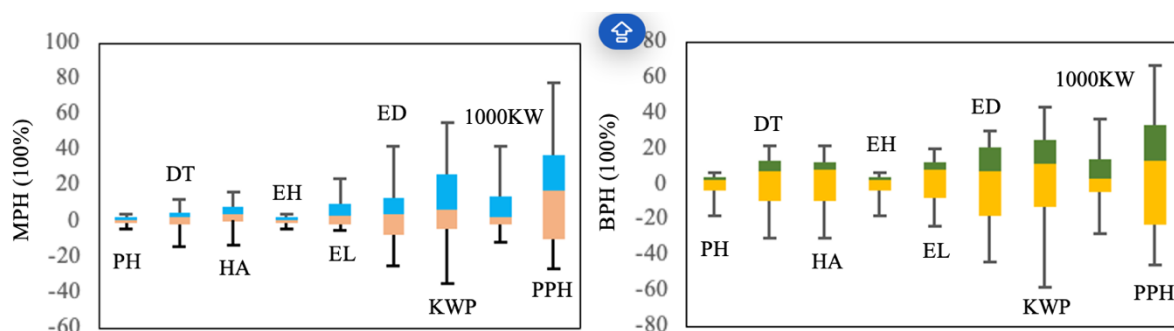


Figure 1. Heterosis 40 jagung hibrida toleran pada cekaman kekeringan. Note: MPH: Mid-Parent Heterosis; BPH: Best-Parent Heterosis; PH: Plant Height; DT: Days to 50% Tasselling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare

Table 6. Mid-Parent Heterosis (MPH) in Hybrid maize (F₁) for all observed characters

Crosses	Percentage (%)								
	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
TS-5-20 × UTM08.5	0.56	3.04	9.86	0.56	12.03	25.47	38.25	7.53	50.30
T2S-5-11 × UTM08.5	0.46	0.13	4.97	0.46	11.35	22.46	32.77	7.08	59.67
DuS-5-24 × UTM08.5	-0.34	-9.69	-5.31	-0.34	-4.93	-25.06	-9.01	-10.17	-27.15
ES-5-24 × UTM08.5	0.77	7.68	16.14	0.77	15.14	31.36	49.55	9.08	28.04
MS-5-06 × UTM08.5	-0.49	-9.53	-4.49	-0.49	1.27	-9.88	-33.56	-4.81	11.26
CS-5-43 × UTM08.5	-1.46	-14.55	-13.47	-1.46	2.03	-16.43	-34.51	-5.21	-15.16
DS-5-3-1 × UTM08.5	2.20	8.46	16.52	2.20	11.20	24.60	34.88	27.76	24.66
GS-4-2-1 × UTM08.5	-0.14	-7.88	-4.99	-0.14	-0.37	-15.02	-8.08	0.53	-21.85
An-S-4-1-5 × UTM08.5	2.77	-1.62	-0.05	2.77	-2.26	-9.66	0.13	-0.03	-11.84
La-S-4-2-4 × UTM08.5	-2.75	-0.33	4.65	-2.75	0.84	-6.11	-2.96	-2.52	-14.86
Bi-S-4-1-10 × UTM08.5	-1.29	-1.84	8.05	-1.29	-4.22	-2.86	-10.94	-0.66	-16.26
Su-S-4-2-4 × UTM 08.5	1.89	4.72	8.60	1.89	8.12	5.37	10.07	11.34	30.69
Su-S-4-1-12 × UTM08.5	1.92	1.99	4.07	1.92	5.16	5.59	15.05	14.08	32.75
Su-S-4-1-15 × UTM08.5	1.58	5.09	7.89	1.58	7.19	4.45	14.77	14.87	21.18
Su-S-4-3-16 × UTM08.5	0.91	3.74	6.67	0.91	9.74	5.46	13.62	39.48	11.01
Lm-S-4-2-12 × UTM08.5	-0.49	-0.77	5.36	-0.49	-2.38	-4.93	-3.07	-0.71	-13.31
Lm-S-4-2-2 × UTM08.5	-0.40	-0.77	0.47	-0.40	-3.41	-3.53	0.89	-0.50	-23.14
Ba-S-4-3-1 × UTM08.5	1.44	2.89	3.87	1.44	2.63	17.70	23.40	13.50	34.13
Ba-S-4-2-2 × UTM08.5	2.59	3.71	5.69	2.59	1.82	24.78	21.10	13.20	29.66
Pl-S-5-2 × UTM08.5	-0.88	1.00	1.35	-0.88	-0.35	-10.00	-2.16	-1.09	-8.06
TS-5-20 × UTM09.6	0.16	1.48	7.82	0.16	13.06	26.44	37.63	15.08	50.58
T2S-5-11 × UTM09.6	0.27	0.75	5.37	0.27	8.84	27.67	27.40	11.40	56.71
DuS-5-24 × UTM09.6	-0.07	-7.25	-5.06	-0.07	-3.02	-21.95	-4.98	-11.71	-8.29
ES-5-24 × UTM09.6	1.33	10.15	15.16	1.33	21.67	34.36	50.93	17.73	66.78
MS-5-06 × UTM09.6	-0.34	1.88	10.26	-0.34	-1.70	-11.44	-30.49	-2.55	-14.48
CS-5-43 × UTM09.6	-1.18	-12.01	-10.78	-1.18	1.56	-9.23	-35.41	-2.69	7.49
DS-5-3-1 × UTM09.6	-1.29	-4.74	0.07	-1.29	-1.01	-7.11	-1.30	2.84	-1.44
GS-4-2-1 × UTM09.6	-1.51	-4.90	-0.66	-1.51	1.67	-12.53	2.30	-0.73	-12.14
An-S-4-1-5 × UTM09.6	-4.76	0.67	0.90	-4.76	-1.94	-4.57	2.07	0.41	8.67
La-S-4-2-4 × UTM089.6	2.28	-2.05	2.39	2.28	-1.86	1.20	7.16	-0.03	9.19
Bi-S-4-1-10 × UTM09.6	-1.01	0.52	8.33	-1.01	-2.73	-4.75	2.90	-0.98	5.33
Su-S-4-2-4 × UTM 09.6	-1.32	-2.77	0.77	-1.32	1.14	-7.07	-8.52	-3.60	14.99
Su-S-4-1-12 × UTM09.6	-0.31	0.86	2.85	-0.31	1.46	-7.33	-4.88	-2.23	-6.56
Su-S-4-1-15 × UTM09.6	-0.79	-1.25	4.29	-0.79	-0.80	-7.31	-4.66	-2.41	-10.06
Su-S-4-3-16 × UTM09.6	-1.08	3.91	7.89	-1.08	-2.08	-5.03	-4.45	-2.75	6.01
Lm-S-4-2-12 × UTM09.6	-0.72	-1.12	1.19	-0.72	0.99	1.17	3.41	-0.65	0.42
Lm-S-4-2-2 × UTM09.6	-1.17	-1.13	5.23	-1.17	0.57	-1.98	-2.94	-1.38	1.14
Ba-S-4-3-1 × UTM09.6	1.22	3.07	3.86	1.22	9.67	-3.09	24.99	13.53	25.55
Ba-S-4-2-2 × UTM09.6	0.88	2.71	2.94	0.88	8.87	-6.12	29.34	16.46	23.44
Pl-S-5-2 × UTM09.6	-0.69	-1.80	-1.53	-0.69	1.64	-3.81	0.02	0.70	0.00
Average	-0.03	-0.44	3.43	-0.03	3.16	1.03	6.02	4.48	10.13

Note: PH: Plant Height; DT: Days to 50% Tasseling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare

The role of genes and distribution of genotype proportions

For all observed characters, the GCA variance value is smaller than the SCA variance value (Table 8). These results show that all characters are more controlled by non-additive gene action (Kabi et al. 2021; Sinare et al. 2024). This result is shown by the value of the dominant variance being greater than the additive variance for all the observed characters. Based on these results, the follow-up action is that improvements in plant character can be carried out by selecting genotypes that are good in appearance.

Line × tester analysis can explain the contribution of strains, testers, and strain × tester interactions. The line had the highest contribution compared to the testers for all plant characters tested. This condition shows that the tester has

little influence on the expression of the observed characters. Line × tester interaction had a lower contribution than the strain contribution to all observed characters. The low contribution to line × tester interaction indicates that line × tester interaction has little influence on the appearance of the observed characters.

Phenotypic correlation

Correlation between characters provides an overview of the relationship and influence of a character with other characters (Jaisi et al. 2021; Zuffo et al. 2023). Correlation analysis between characters functions to identify closely related characters, thereby helping to select and improve plant characters. In addition, correlation analysis can help reveal patterns of relationships between plant characters

(Amzeri et al. 2022b). A negative correlation indicates that increasing one character will decrease another character, while a positive correlation indicates that increasing one character will increase another correlated character (Faysal et al. 2022; Abikkumar et al. 2023). Figure 3 shows a positive correlation between the characters tested except that plant height and 1000-weight kernel have a negative correlation. In positive correlation, almost all the characters were significantly positively correlated except days to 50% tasselling with the 1000-weight kernel, harvest age with the 1000-weight kernel, ear height with the 1000-weight kernel, ear height with days to 50% tasselling, and ear height with harvest age.

Correlation analysis between characters is very useful for plant breeders in selecting characters that are positively

and negatively correlated with characters of economic value. In this research, the character of production per hectare is a character that has economic value. Plant breeders will utilize positive and negative correlations of other characters with production per hectare character to save time, costs, and energy in implementing plant selection (Novrika et al. 2016; Karyawati and Puspitaningrum 2021; Amzeri et al. 2022b). The research results showed that the character of production per hectare had a significant positive correlation with the character of plant height, ear height, days to 50% tasselling, harvest age, and 1000-weight kernel. Indirect selection on the character of plant height, ear height, days to 50% tasselling, harvest age, and 1000-weight kernel will impact production per hectare.

Table 7. Best-Parent Heterosis (BPH) in Hybrid maize (F₁) for all observed characters

Crosses	Percentage (%)								
	PH	DT	HA	EH	EL	ED	KWP	1000KW	PPH
TS-5-20 × UTM08.5	-0.16	-6.57	-5.57	-0.16	3.94	3.08	15.99	8.70	29.02
T2S-5-11 × UTM08.5	-0.31	-10.96	-10.48	-0.31	3.66	1.83	17.08	1.27	40.68
DuS-5-24 × UTM08.5	-1.12	-20.38	-18.50	-1.12	-23.56	-44.08	-23.30	-26.71	-37.03
ES-5-24 × UTM08.5	0.88	-10.73	-9.36	0.88	-2.99	1.90	12.90	3.08	-2.89
MS-5-06 × UTM08.5	-2.60	-18.85	-19.51	-2.60	-21.51	-25.63	-54.27	-9.72	-21.57
CS-5-43 × UTM08.5	-15.19	-30.47	-30.54	-15.19	-8.95	-31.59	-58.51	-11.34	-45.78
DS-5-3-1 × UTM08.5	2.50	-2.84	-0.11	2.50	2.82	5.18	15.55	10.74	9.33
GS-4-2-1 × UTM08.5	-1.17	-18.18	-18.28	-1.17	-10.99	-30.08	-24.84	2.71	-35.06
An-S-4-1-5 × UTM08.5	-3.53	-0.65	0.67	-3.53	-2.97	-20.20	-12.51	0.26	-18.30
La-S-4-2-4 × UTM08.5	-14.09	-2.40	-1.00	-14.09	-3.13	-13.73	-13.82	-0.75	-21.31
Bi-S-4-1-10 × UTM08.5	-3.32	4.83	5.47	-3.32	-8.07	-8.11	-24.13	-1.53	-24.59
Su-S-4-2-4 × UTM 08.5	0.42	9.66	10.59	0.42	0.65	2.42	6.32	7.76	12.14
Su-S-4-1-12 × UTM08.5	0.04	7.03	7.02	0.04	-2.06	2.16	11.47	16.91	8.65
Su-S-4-1-15 × UTM08.5	1.29	1.97	10.59	1.29	-0.44	0.37	12.33	18.81	-2.19
Su-S-4-3-16 × UTM08.5	0.32	9.66	9.70	0.32	0.94	2.47	11.42	31.17	-10.08
Lm-S-4-2-12 × UTM08.5	-1.62	-1.97	-0.33	-1.62	-8.56	-11.24	-4.89	-3.12	-22.49
Lm-S-4-2-2 × UTM08.5	-1.49	-1.97	-5.57	-1.49	-11.11	-8.69	1.30	-3.60	-32.48
Ba-S-4-3-1 × UTM08.5	-0.06	-2.41	-1.34	-0.06	0.11	2.88	12.28	13.21	25.16
Ba-S-4-2-2 × UTM08.5	2.41	-1.74	-0.56	2.41	-1.07	7.06	11.74	12.02	22.23
Pl-S-5-2 × UTM08.5	-3.47	-0.22	0.67	-3.47	-2.60	-20.72	-8.06	-3.90	-11.32
TS-5-20 × UTM09.6	-2.06	-6.37	-6.39	-2.06	6.40	8.73	21.75	16.65	34.08
T2S-5-11 × UTM09.6	-1.81	-8.88	-9.25	-1.81	2.78	11.22	18.60	5.03	43.33
DuS-5-24 × UTM09.6	-0.81	-16.86	-17.47	-0.81	-21.10	-39.46	-15.35	-27.74	-17.79
ES-5-24 × UTM09.6	0.85	-7.28	-9.36	0.85	3.79	8.66	18.83	10.92	30.31
MS-5-06 × UTM09.6	-3.40	-7.05	-6.16	-3.40	-22.98	23.48	-50.33	-7.83	-38.10
CS-5-43 × UTM09.6	-15.51	-27.34	-27.74	-15.51	-8.13	-22.23	-57.93	-9.26	-30.01
DS-5-3-1 × UTM09.6	-5.41	-13.21	-13.35	-5.41	-7.16	-17.77	-10.64	-11.10	-10.25
GS-4-2-1 × UTM09.6	-4.98	-14.10	-13.70	-4.98	-7.91	-24.65	-11.95	-3.20	-24.41
An-S-4-1-5 × UTM09.6	-18.14	3.65	2.85	-18.14	0.33	-11.34	-5.60	0.99	-3.05
La-S-4-2-4 × UTM089.6	-3.95	-2.27	-2.05	-3.95	4.00	-1.95	0.97	-2.01	-2.84
Bi-S-4-1-10 × UTM09.6	-1.63	9.57	6.97	-1.63	3.16	-4.80	-7.37	-2.60	-8.59
Su-S-4-2-4 × UTM 09.6	-4.73	3.88	3.88	-4.73	11.08	-14.33	-16.82	-5.60	-4.67
Su-S-4-1-12 × UTM09.6	-3.18	7.99	7.08	-3.18	11.36	-14.97	5.51	-4.74	-25.95
Su-S-4-1-15 × UTM09.6	-2.28	6.40	8.22	-2.28	9.25	-15.50	4.49	-5.63	-29.65
Su-S-4-3-16 × UTM09.6	-2.50	12.08	12.33	-2.50	9.09	-12.51	-11.77	-8.69	-16.81
Lm-S-4-2-12 × UTM09.6	-3.79	-0.44	-3.19	-3.79	10.12	-1.37	-1.88	-2.39	-13.45
Lm-S-4-2-2 × UTM09.6	-4.07	-0.45	0.00	-4.07	11.97	-2.02	-7.11	-4.00	-14.27
Ba-S-4-3-1 × UTM09.6	0.62	-0.45	-0.23	0.62	8.60	-10.95	30.04	13.95	21.95
Ba-S-4-2-2 × UTM09.6	0.20	-0.91	-2.05	0.20	7.38	-15.42	26.30	12.99	21.19
Pl-S-5-2 × UTM09.6	-4.18	-1.13	-1.03	-4.18	0.85	-10.90	-1.49	-2.87	-0.41
Average	-3.02	-3.78	-3.68	-3.02	-1.58	-9.99	-4.19	0.72	-5.68

Note: PH: Plant Height; DT: Days to 50% Tasseling; HA: Harvest Age; EH: Ear Height; EL: Ear Length; ED: Ear Diameter; KWP: Kernel Weight per Plant; 1000KW: 1000-Kernel Weight; PPH: Production Per Hectare

Table 8. Genetic components of all characters observed using line × tester method

Characters	Variance				Contribution (%)		
	GCA	SCA	Aditif	Dominan	Lines	Testers	Lines × Testers
Plant height	0.49	0.70	30.36	0.00	100.00	0.00	0.00
Days to 50% tasselling	0.15	0.21	1.28	7.67	83.43	2.51	14.06
Harvest age	0.14	0.20	4.73	34.49	81.79	2.18	16.03
Ear height	0.31	0.44	1.27	8.13	84.82	0.29	14.89
Ear length	0.08	0.11	0.14	0.33	91.78	1.32	6.90
Ear diameter	0.04	0.06	0.03	0.14	77.11	10.31	12.58
Kernel weight per plant	1.56	2.20	13.49	29.99	87.82	4.97	7.21
1000-kernel weight	4.16	5.89	29.49	288.58	76.39	2.94	20.67
Production per hectare	0.05	0.07	0.07	0.48	84.45	0.41	15.14

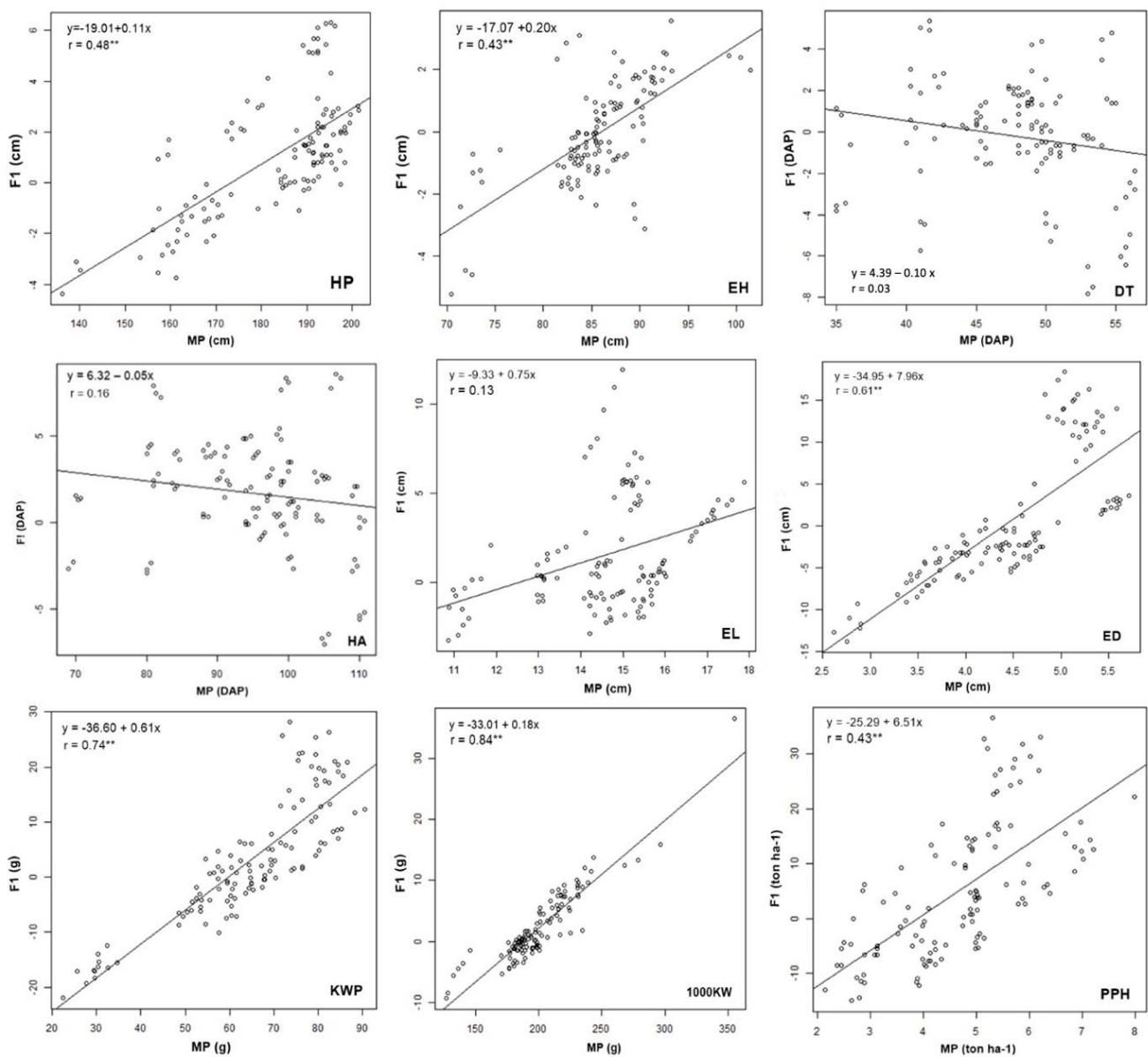


Figure 2. Linear regression between Mid-Parent (MP) and hybrid performance (F1) of 40 combinations. Note: PH: Plant Height (cm); DT: Days to 50% Tasselling (days); HA: Harvest Age (days); EH: Ear Height (cm); EL: Ear Length (cm); ED: Ear Diameter (cm); KWP: Kernel Weight per Plant (g); 1000KW: 1000-Kernel Weight (g); PPH: Production Per Hectare (tons); r: Coefficient of correlation; *: Significant at $P \leq 0.05$; **: Significant at $P \leq 0.01$

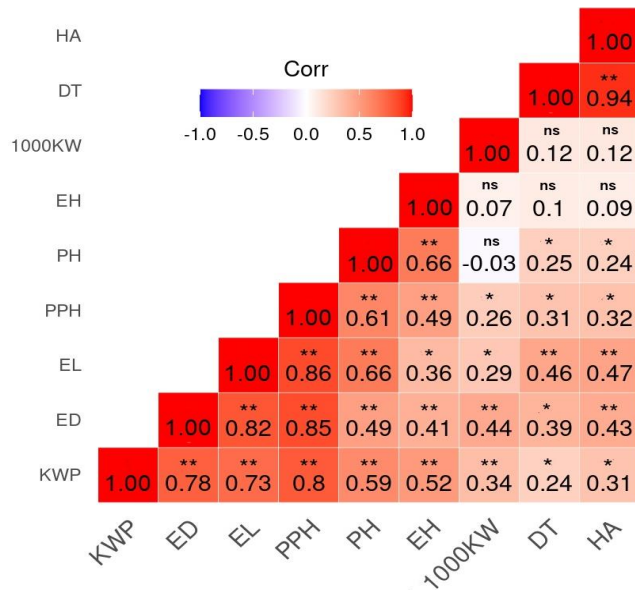


Figure 3. Phenotypic correlation among the independent and dependent traits in hybrid maize. Note: PH: Plant Height (cm); DT: Days to 50% Tasselling (days); HA: Harvest Age (days); EH: Ear Height (cm); EL: Ear Length (cm); ED: Ear Diameter (cm); KWP: Kernel Weight per Plant (g); 1000KW: 1000-Kernel Weight (g); PPH: Production Per Hectare (tons); ns: $p \geq 0.05$; *: $p < 0.05$; **: $p < 0.01$

In conclusion, the direction for developing maize plant varieties on dry land is to develop hybrid maize varieties that are in early maturity and have high production. Lines that have a significant negative GCA value in harvest age character and can be used as parents in assembling early maturity maize varieties are T2S-5-11, DuS-5-24, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-12, and Su-S-4-1-15. Lines with a large positive GCA value and can be used as parents for assembling maize varieties with high production character are T2S-5-11, Su-S-4-2-4, Su-S-4-1-12, Su-S-4-1-15, and Su-S-4-3-16. The crosses T2S-5-11 \times UTM08.5, Su-S-4-2-4 \times UTM08.5, and Su-S-4-1-15 \times UTM08.5 had significant negative SCA values for harvest age and significant positive SCA values for the production per hectare character so that the three cross combinations can be used as candidates for the formation of early maturity and high production hybrid maize varieties. MPH and BPH values for harvest age characters with negative values are CS-5-43 \times UTM08.5, CS-5-43 \times UTM09.6, and DuS-5-24 \times UTM08.5. The MPH values for production per hectare with positive values are ES-5-24 \times UTM09.6, T2S-5-11 \times UTM08.5, and T2S-5-11 \times UTM09.6. Furthermore, the BPH values for production per hectare character with positive values are T2S-5-11 \times UTM09.6, T2S-5-11 \times UTM08.5, and TS-5-20 \times UTM09.6.

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