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Application of graphical analysis and principal components to identify the effect of genotype × trait in maize hybrids

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Abstract

In order to identify the effect of genotype × trait, 20 maize (*Zea mays* L.) hybrids were cultivated and investigated in a randomized complete block design in three replications in the Karaj region. The results of the analysis of variance showed that the effect of genotype in terms of all traits except for the traits of days until the tassel dries, peduncle outside the flag leaf, tassel length, the number of fill seeds, and the depth of the seeds are significantly different. Based on the mean comparison done by Duncan's method, G3, G6, G7, and G4 genotypes were identified as favorable hybrids. Based on the graphic analysis, the genotypes G5, G4, G6, G3, G9, and G14 can be identified as desirable hybrids. The correlation diagram indicated that the grain yield trait has a positive correlation with tassel length, leaf length, leaf width, and leaf surface traits. Based on the principal component analysis, the first 10 components explained more than 74% of the data variance. The traits were classified into 10 components: components of ear characteristics, time characteristics in terms of maturity, leaf characteristics, characteristics of maize plant 1 (cob corn diameter, peduncle length, and grain yield traits), characteristics of maize plant 2 (number of tassel branches, leaf surface, and grain yield traits), physiological characteristics and germination, the crown part of the ear characteristics, grain characteristics, grain yield, and characteristics of the ear head. The experiment results indicated that G8, G15, G1, and G6 hybrids were more favorable in terms of grain yield trait.

Abbreviations: GGE, genotype × genotype × environment; GT, genotype × trait.

1 | INTRODUCTION

Maize (*Zea mays* L.) is a crucial crop worldwide (Desoky et al., 2021). It holds strategic importance in Iran, cultivated in all provinces, providing income for farmers (Sheikhzeinoddin & Fathi, 2021). In Alborz province, Karaj region, 2500 ha of maize yield an estimated 500 tones annually (Agricultural Statistics, 2022). Maize is vital for human and animal nutrition, offering high food value (da Silva et al., 2018). It is used to produce various products like oil, starch, and ethanol (Alhadi et al., 2013).

Various statistical methods identify trait-genotype relationships in plants, with principal component analysis (PCA) being popular for large, correlated datasets (Kherif & Latypova, 2020). PCA reduces data dimensions while retaining information. In the study, PCA and correlation were used to examine traits, showing these methods' usefulness in selecting treatments and genotypes (Semeskandi et al., 2023).

Genotype × trait (GT) biplot, a genotype × genotype × environment (GGE) biplot method, is valuable for studying multi-trait data (Yan & Kang, 2002). It evaluates genotypes based on multiple traits, identifying superior ones and distinguishing favorable traits (Mohammadi & Amri, 2013). This graphical method selects the best genotypes based on evaluated traits (Sharifi & Ebadi, 2018) and identifies genotype-trait relationships (de Oliveira et al., 2018; Al-Naggar et al., 2020). GT biplot can select high-performing traits (Swelam, 2012). In GT biplot, genotypes are lines, and traits are testers (Yan & Rajcan, 2002).

To determine the correlation of traits, genotype-trait biplot diagrams are used, which are obtained from the GGE biplot method (Akçura & Kokten, 2016). Mousavi et al. (2020) screened maize hybrids for desirable traits. Khatibi et al. (2022) used PCA and correlation analysis to select superior genotypes. Santana et al. (2021) used GT biplot to compare maize genotypes and interpret data with polygon diagrams. Khatibi et al. (2023) used GT biplot to select drought-resistant cultivars and examine agronomic traits' effects on yield. The researcher has experience with GT biplot for matching hybrids to trait performance (Illés et al., 2020; KiliÇ, 2014; S. Shojaei et al., 2022).

Santana et al. (2021) used the GT biplot method in maize cultivars to investigate the correlation between traits and compared 11 maize genotypes in terms of different agricultural traits and used graphical analysis such as polygon diagrams to interpret their data. In another study with the aim of investigating yield and yield components under drought stress conditions, it was conducted on corn cultivars through genotype and trait biplot analysis (GT biplot), drought stress-resistant cultivars were selected, and the effect of different agronomic traits on yield traits was examined (Khatibi et al., 2023). Engida et al. (2024) evaluated maize hybrids under stress, recommending stable, high-yielding hybrids for sub-Saharan Africa (Engida et al., 2024). Mebratu et al. (2024) assessed quality protein maize hybrids, identifying promising inbred lines for breeding improved varieties (Mebratu et al., 2024). This study explores genetic factors and agricultural traits interactions to optimize breeding programs and increase crop productivity. Understanding these interactions aids in developing high-yielding hybrids and improving corn breeding strategies.

Core Ideas

- The interaction between genotype and trait is very effective in selecting genotypes for breeding programs.
- Trait relations and grain yield evaluation are key for breeding program genotype selection.
- Genotype × trait biplot method is very important in examining genotypes based on different traits and their relationships.

This experiment was conducted in order to investigate the complex relationships between genetic factors and different agricultural characteristics, and understanding these interactions is necessary to optimize breeding programs and increase crop productivity. By elucidating the mechanisms of genotype and trait interaction, this study will help to facilitate the development processes of high-yielding hybrids and desirable cultivation characteristics and improve the breeding strategy in corn plant improvement programs.

The purpose of this research is to: (1) examine the effect of GT using the GT biplot method, (2) examine the yield and its components and select traits that affect grain yield, (3) select the optimal genotypes in terms of traits, and (4) examine the correlation between the traits evaluated in the experiment.

2 | MATERIALS AND METHODS

2.1 | Experimental site

This experiment was conducted in the Karaj region. Karaj has a longitude of 35.8439° N and a latitude of 50.9715° E, with an altitude of 1312 m above sea level and an average annual rainfall of 247.3 mm. Figure 1 shows the characteristics of temperature and humidity of the experimental area in 6 months.

2.2 | Plant materials

In order to investigate this experiment, 20 maize hybrids were used. Table 1 shows the code, name, and characteristics of the hybrids studied in the experiment.

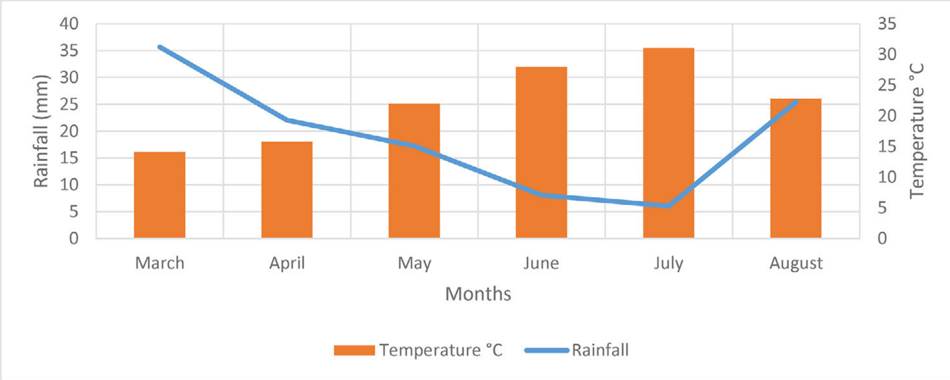

FIGURE 1 Characteristics of temperature and humidity of the experimental area in 6 months.

TABLE 1 Code, name, and characteristics of maize hybrids cultivated in the experiment.

Genotype No.	Genotype	Genotype No.	Genotype
G1	KSC704	G11	KLM 75010/4-4-1-2-1-1 X MO17
G2	KSC700	G12	KLM 75010/4-4-1-2-1-1 X B73
G3	KSC720	G13	BC666
G4	NSX K19/20	G14	BC678
G5	KLM 76002/4-2-1-2-1-1 X K 19/1	G15	ZP677
G6	NS X K 19/1	G16	ZP684
G7	K 47/2-2-1-2-1-1-1 X K 19/1	G17	G-3393
G8	KLM 76005/7-1-2-1-1-1 X K 19/1	G18	NS540
G9	K 47/2-2-1-2-3-1-1 X K 19/1	G19	G-3261
G10	K 74/1 X MO17	G20	G-72019

2.3 | Experimental design and treatment details

This experiment was conducted in order to investigate the effect of GT as well as evaluate its performance and its components on 20 maize hybrids in the form of a randomized complete block design in three replications. After performing the steps of land preparation such as plowing, disking, and smoothing, the planting operation was done manually. Each experimental plot had four rows of crops 2 m long and 75 cm apart. The distance between each plot was considered to be 2 m. Irrigation was carried out normally and regularly, and most of the examined traits were measured on the plant before harvest. The traits of ear length, 1000-seed weight, number of seeds per ear row, number of seed rows per ear, seed moisture content percentage, cob corn content, ear diameter, cob corn diameter, seed depth, and grain yield were also measured after harvest. For this purpose, random sampling was done from the middle two rows of five plants. Table 2 shows the code and characteristics of the attributes evaluated in the experiment.

2.4 | Data collection and analysis

In order to study the effect of GT, random sampling was done from the middle two rows of five plants. The following method was used (Yan & Rajcan, 2002):

$$\frac{T_{ij} - \bar{T}_j}{s_j} = \lambda_1 \zeta_{i1} \tau_{j1} + \lambda_2 \zeta_{i2} \tau_{j2} + \varepsilon_{ij} \tag{1}$$

where T_{ij} is the average value of genotype i for trait j, $\bar{T}_j$ is the average value of trait j over genotype, s_j is the standard deviation of trait j among the genotype averages, ζ_{i1} and ζ_{i2} are the PC1 and PC2 scores, respectively, for genotype i, τ_{j1} and τ_{j2} are the PC1 and PC2 scores, respectively, for trait j, and ε_{ij} is the residual of the model associated with the genotype i in trait j.

Also, due to the difference between the units in the evaluated traits, standardization was used to eliminate the units, which was done by the following formula:

$$Z = \frac{X - \mu}{\sigma} \tag{2}$$

TABLE 2 Code and name of traits evaluated in the experiment.

Traits code	Traits	Traits code	Traits
DGM	Day to germinate maize	TL	Tassel length
DV10	Days until V10-ten leaf	LCAT	The length of the central axis of tassel
DT	The days until tasseling	NTB	Number of tassel branch
DS	The days until pollination	NFS	Number of fill seeds
DP	The days until the end of pollination	WTG	Weight of 1000 seeds
DTD	The days until tassel dries	NSPR	Number of the seeds per row
DPM	The days until the physiological maturity	NRE	Number of the row in ear
PH	Plant height	MCS	Seed Moisture content
EL	Ear length	CCC	Cob corn content
LL	Leaf length	DE	Diameter ear
LW	Leaf width	CCD	Cob corn diameter
LS	Leaf surface	SD	Seed deep
PL	Peduncle length	YLD	Grain yield
POFL	Peduncle outside the flag leaf		

where Z is the standard score, X is the initial data of the trait, μ is the mean of the trait, and σ is the standard deviation of the trait.

2.5 | Statistical analysis

For the statistical analysis of data from variance analysis, mean comparison by the Duncan method, PCA, and graphical analysis with GT biplot method, which includes polygon diagram, hybrid stability diagram based on evaluated traits, and hybrid ranking diagram based on the ideal hybrid, the grouping of the hybrids was based on the studied traits and the correlation diagram between the traits was used.

Excel, SAS.V9.1, and Genstat.V12.1 software were used to analyze the data obtained from the experiment.

3 | RESULTS AND DISCUSSION

3.1 | Agro-morphological traits

The results of the analysis of variance performed at the probability level of 0.01 indicated that the effect of the block in the traits of days to germinate maize, day until V10-ten leaf, day until tasseling, days until pollination, days until the physiological maturity, leaf width, tassel length, the length of the central axis of tassel, number of the seeds per row, cob corn content, and cob corn diameter were significant. The effect of genotypes also showed a significant difference in terms of all the traits except for the traits of days until tassel dries, peduncle outside the flag leaf, tassel length, number of fill seed, and seed depth. The lowest percentage of the coefficient of variation was related to the trait of days until V10-ten leaf collar (2.8), and the highest percentage of the coefficient of variation was related to the trait of number of fill seed (28.5) (Table 3). In a study that was conducted on the interaction effect of genotype and trait on maize hybrids in several regions over 2 years, it was concluded that traits such as ear length, ear diameter, number of grains per row, and grain yield had significant differences in all experimental regions and the results obtained. The findings of the present study were consistent with the results of these researchers (S. H. Shojaei et al., 2020). The mean comparison was done using Duncan's method on the traits and genotypes evaluated in the experiment. Based on this, genotypes G14, G19, and G2 in terms of day to germinate maize trait, genotypes G6, G3, and G1 in terms of days until V10-ten leaf collar trait, genotypes G9, G1, and G5 in terms of the days until tasseling trait, genotypes G4, G5, and G3 in the days until pollination trait, G1, G5, and G4 genotypes in terms of the days until the end of pollination trait, G14, G20, and G11 genotypes in the days until tassel dries trait, G10, G12 genotypes and G2 as days until the physiological maturity trait, G20, G3, and G17 genotypes in plant height trait, G4, G9, and G16 genotypes in ear length trait, G11, G17, and G6 genotypes in terms of leaf length trait, G1, G18 genotypes and G3 in terms of leaf width trait, G11, G1, and G19 genotypes in leaf surface trait, G12, G9, and G14 genotypes in peduncle length trait, G7, G14, and G8 genotypes in peduncle outside the flag leaf trait, genotypes G18, G4, and G13 in terms of the tassel length trait, genotypes G13, G15, and G7 in terms of the length of the central axis of the tassel trait, genotypes G5, G2, and G1 in the number of tassel branches trait, genotypes G3, G9, and G6 in terms of the number of fill seeds trait, genotypes G17, G2, and G3 in terms of 1000-seed weight trait, genotypes G3, G5, and G8 in terms of number

TABLE 3 Variance analysis of investigated traits in 20 maize hybrids in terms of studied traits.

Variable	df	DGM	DV10	DT	DS	DP	DTD	DPM	PH	EL	LL	LW	LS	PL	
Block	2	0.35*	126.4**	57.05*	67.5**	102.8*	2.3^{ns}	306.6*	776.4^{ns}	7.6^{ns}	52.8^{ns}	5.8*	4127^{ns}	18.1^{ns}	
Genotypes	19	0.36*	919*	11.6**	7.5*	11.5*	1.17^{ns}	37.6*	445.8*	3.3*	49.3*	2.02*	3457*	17.2*	
Error	38	0.36	4.9	6.8	5.3	9.3	1.8	56.8	413.2	3.6	53.7	0.7	7216	17.5	
CV (%)		5.2	2.8	3.6	3.11	3.8	1.33	5.8	12.2	12.3	10.5	9.7	18.03	13.8	
	df	**POFL**	**TL**	**LCAT**	**NTB**	**NFS**	**WTG**	**NSPR**	**NRE**	**MCS**	**CCC**	**DE**	**CCD**	**SD**	**YLD**
Block	2	5.3^{ns}	83.6*	9.8*	2.3^{ns}	31393^{ns}	14.9^{ns}	47.4*	2.2^{ns}	12.3^{ns}	423.1**	0.27^{ns}	0.12*	0.1^{s}	3.6^{ns}
Genotypes	19	6.1^{ns}	12.3^{ns}	3.9*	1.7*	12146^{ns}	14.6*	35.03*	6.7*	4.9**	42.6**	0.11*	0.04*	0.04^{ns}	7.5**
Error	38	5.03	24.7	3.7	1.5	15828	14.3	54.8	4.41	7.9	44.1	0.13	0.03	0.04	8.7
CV (%)		15.4	11.9	6.7	14.8	16.1	10.3	17.9	14.17	17.8	16.61	8.7	8.3	17.6	18.1

Abbreviations: CCC, cob corn content; CCD, cob corn diameter; CV, coefficient of variation; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

*Significant at 0.05. **Significant at 0.01.

of the seeds per row trait, genotypes G4, G5, and G6 in the number of the rows in ear trait, genotypes G14, G7, and G6 in terms of seed moisture content trait, genotypes G12, G18, and G15 in cob corn content trait, G3, G6, and G9 genotypes in terms of ear diameter trait, G12, G7, and G16 genotypes in cob corn diameter trait, G6, G4, and G14 genotypes in grain depth trait, and G8, G15, and G1 genotypes in terms of grain yield trait had high favorability compared to other hybrids evaluated in the experiment (Table 4). The comparison of favorable and unfavorable hybrids in terms of evaluated traits is presented separately in Table 5.

According to the examination of the genotypes in terms of all the evaluated traits, G3, G6, G7, and G4 genotypes can be selected as desirable hybrids in terms of this analysis.

3.2 | Principal component analysis

The principal component analysis is a technique that identifies plant traits that contribute the most for the observed variation within a group of genotypes. This tool has a practical application in the selection of best genotypes for breeding purpose (Hemavathy, 2020). Based on the principal component analysis done on the traits studied in the experiment, the first 10 components explained more than 74% of the variance of the total data. The first component covers more than 16% of the variance of the data, and in this component, the traits of number of seeds per row (0.35), ear diameter (0.30), peduncle outside the flag leaf (0.29), and cob corn diameter (0.28) had the most positive effect. The second component explained more than 10% of the variance of the total data, and in this component, the traits of days until V10-ten leaf collar (0.43), days until pollination (0.43), and days until the end of pollination (0.38) had the most positive effect. The third component justified 8% of the variance of the data, and based on this, the traits of leaf length (0.51), leaf width (0.36), and leaf surface (0.33) had the most positive effect on this component. Based on the fourth component, which justified 7% of the variance of the data, the traits of cob corn diameter (0.29), peduncle length (0.28), and grain yield (0.27) had the most positive effect. The fifth component also covered 4.6% of the variance of the total data, and in this component, traits of the number of tassel branches (0.41), leaf surface (0.42), and grain yield (0.34) had the most positive effect. The sixth component justified 6% of the variance of the data, and in this component, the traits of days until the physiological maturity (0.5) and days to germinate maize (0.34) had the most positive effect. The seventh component justified more than 5% of the variance of the data, and in this component, the traits of the peduncle length (0.41) and the days until tassel dries (0.38) had the most positive effect. The eighth component explained 4.9% of the variance of the data, and in this component, ear diameter (0.39) and seed depth (0.34) traits had the most positive effect. The ninth component explained 4.3% of the variance of the data, and in this component, the traits of 1000-seed weight (0.71) and grain yield (0.31) had the most positive effect. The 10th component explained 4% of the variance of the data, and in this component, the traits of the days until tassel dries (0.54) and cob corn diameter (0.2) had the most positive effect. Based on this, the first component can be named as "ear characteristics," the second component as "time characteristics in terms of processing," the third component as "leaf characteristics," the fourth component as "maize characteristics 1", the fifth component as "maize plant characteristics 2", the sixth component as "physiological and germination characteristics," the seventh component as "maize crown characteristics," the eighth component as "seed characteristics," the ninth component was named as "grain yield" and the 10th component as "ear head characteristics" (Table 6). In the research that was

TABLE 4 Comparison of mean by Duncan's method in the experiment of 20 maize hybrids in terms of the traits evaluated in the experiment.

	Rate (1–20)	DGM	DV10	DT	DS	DP	DTD	DPM	PH	EL	LL	LW	LS	PL
G1	8	11.6bc	80.3abc	74.3a	75.3abc	84.6a	100c	131abc	158.6cde	14.4cd	72.6abc	9.6a	513.1ab	13.8d
G2	9	12ab	77.6bcde	72.3bc	76abc	80bcd	101bc	132.3ab	149.3de	15.6abc	69.8bcd	9.2abc	498bcd	16.5bcd
G3	1	11.2bc	80.6ab	73.6abc	76.3abc	79.3bcde	101bc	130.3bc	180.6ab	17.3a	58.5e	9.4ab	421de	18.7bc
G4	4	11.4bc	78abcde	74ab	77a	83abc	101bc	131.3abc	170.3abc	15.3abc	70.3bc	9.06abc	427de	17.1bcd
G5	12	11.2bc	78abcde	74.3a	76.6ad	83.6ab	101bc	129.3bc	163bcde	14.8bcd	67.2cde	8bcd	464.3cde	16.5bcd
G6	2	11.6bc	82.3a	73.3abc	75abc	81.6abcd	103.6ab	129.3bc	178abc	15.2bc	74.8ab	7.9bcd	485.6bcde	15.2bcd
G7	3	11bc	77bcde	70cd	73bcd	82abcd	103.6ab	129bc	168.6bc	15.8abc	70.3bc	9.2abc	414e	20.5bc
G8	10	11.6bc	78abcde	72bc	74.6bc	78.6cde	100c	130.3bc	156.3cde	16.2ab	71bc	8.5bcd	483.9bcde	17.2bcd
G9	7	10d	78abcde	74.6a	73.6bcd	80bcd	104ab	126.6cd	166bcd	17.2a	68.3bcde	6.3d	446cde	23.9b
G10	16	12ab	79.3abcd	73.3abc	71e	80.6bcd	101bc	142.3a	134.6e	14.5cd	68.2bcde	7.7cd	446cde	15.1cd
G11	13	11bc	74.6e	68.6d	73.6bcd	77e	104.3a	130bc	156.3cde	16.5ab	75.4a	9.2abc	531.1a	19.9bc
G12	11	11.6bc	77.3bcde	72.6abc	73bcd	80.3bcd	103.6ab	134.6ab	164bcd	12.9d	66.4cde	8.3bcd	495.6bcd	35.4a
G13	14	10.5bcd	76cde	69cd	74bc	78cde	101bc	129.3bc	168bc	15.8abc	69.1bcd	8.8bcd	477.2cde	16.9bcd
G14	5	12.3a	78.6abcde	72.6abc	74.3bc	80.6bcd	104.3a	127.6cd	157.6cde	16.6ab	65.1de	8bcd	479.6cde	21.2b
G15	15	11.6bc	79abcde	71.3bcd	72de	79.3bcde	101bc	128bcd	167bcd	15.3bc	65.2de	8.1bcd	438.2cde	16.7bcd
G16	6	11.6bc	79abcde	72bc	74bc	80.6bcd	102bc	128bcd	173.6ab	16.8ab	69.9bcd	9.03abc	438.2cde	17.1bcd
G17	17	10.5bcd	75.6de	71bcd	74bc	79bcde	102bc	126.6cd	180ab	15.3bc	75.1a	9.03abc	489.2bcde	17.2bcd
G18	20	11.3bc	79.3abcd	70.3cd	72.3cde	80bcd	101bc	126cd	162bcde	15.3abc	73.4ab	9.6a	503abcd	14.3cd
G19	19	12.3a	76.3bcde	69.6cd	72.6bcde	81.3abcd	102bc	128bcd	178abc	15.1bc	66.1cde	7.8cd	506abc	17.1bcd
G20	18	12ab	77bcde	68.6d	72de	77.3de	104.3a	129bc	185.6a	14.9bc	70.4bc	8.9bc	476.2cde	17.5bcd

	POFL	TL	LCAT	NTB	NFS	WTG	NSPR	NRE	MCS	CCC	DE	CCD	SD	YLD
G1	4.6 cd	39.8bcd	28.3bc	9ab	482.3ab	283d	21.9d	14.8bc	14.7cd	22.1abc	4.1ab	2.05c	1.04ab	9.4ab
G2	3.1d	42.2ab	29abc	9.3ab	409cd	333bc	27.4bc	12.6cd	15.8bc	20bcde	3.9b	2.36abc	0.88cd	8.5abc
G3	4.5 cd	43.9ab	28.6bc	8.6abc	539a	350b	32.4a	15.8abc	16.1abc	16.7de	4.56a	2.41ab	1.02ab	4.9cd
G4	6.3bc	41.5abc	29.3ab	8bc	474abc	291.7cd	27.8bc	17.6a	16.4ab	22abc	4.1ab	2.28bc	1.13a	5.9bcd
G5	4.8 cd	40.1bcd	27.3bc	10.3a	473abcd	300cd	32.4a	16.6ab	15.6bcd	18.4cde	4.1ab	2.28bc	0.92bc	8abc
G6	4.8 cd	40.3bcd	27bcd	8.6abc	495.3ab	316bc	29.6bc	16.4ab	17.3ab	20.9bcd	4.5a	2.28bc	1.15a	6.9bcd
G7	9.2a	41.3abc	29.6ab	7c	481.3ab	333bc	29.4bc	15.6abc	17.9a	19.7cde	4.4ab	2.43ab	0.98bc	7.9bc
G8	7.6abc	43ab	28.3bc	9ab	442bcd	283d	31.9ab	15.3abc	16.2abc	16.9de	3.9b	2.3abc	0.9bcd	10.1a
G9	7.5abc	38.9cd	29.3ab	8.3abc	532.7a	316bc	28.8bc	14bc	16.2abc	16.1de	4.5a	2.35abc	1.08a	6.8bcd
G10	5.9bcd	42.7ab	28.6bc	8.3abc	346cd	316bc	24.9cd	16.1ab	13.7d	20.5bcde	4.4ab	2.36abc	0.98bc	5.2bcd
G11	7.4abc	41.7abc	28.6bc	9ab	452bcd	300cd	30bc	13.8bcd	16abc	12.8e	4.1ab	2.37abc	0.84cd	8.5abc
G12	6.3bc	40.7abcd	29abc	7.6bc	270d	300cd	23.4cd	15.8abc	13.8cd	29a	4.2ab	2.47a	0.98bc	9.2ab
G13	5.1bcd	43.8ab	31.3a	8bc	449bcd	316bc	30.5abc	14.4bc	16.8ab	18.3cde	4.4ab	2.28bc	1.02ab	6.8bcd
G14	8.5ab	41.7abc	28.6bc	8.3abc	454.7bcd	325bc	30.8ab	15.4abc	18.6a	20.6bcd	4.2ab	2.21bc	1.1a	4.7cd
G15	5.3bcd	37.1d	30.3ab	8bc	475.3abc	350b	30.6ab	14.4bc	14.6cd	23.6ab	4.4ab	2.24bc	0.93bc	9.5ab
G16	7.5abc	42.6ab	29.3ab	7.3bc	472.8abcd	350b	28.6bc	15.5abc	15.8bc	19.7cde	4.2ab	2.42ab	0.98bc	9ab
G17	7.1abc	43.8ab	27bcd	8bc	422cd	370a	25.3bcd	14.3bc	16.1abc	13.9e	4.1ab	2.28bc	0.6d	6.8bcd
G18	4.7 cd	46.2a	26.6cd	7.6bc	333cd	316bc	22.2cd	13.4cd	13.9cd	24.6ab	4.1ab	2.07c	0.6d	4.2d
G19	5.4bcd	38.9cd	28bc	8bc	399cd	333bc	23.5cd	10.8d	15.4bcd	22.4abc	4.04ab	2.16bc	0.78cd	7.5bcd
G20	6.2bc	39.8bcd	29.3ab	8bc	400cd	380bcd	25cd	14.6bc	15.5bcd	18cde	4.07ab	2.18bc	0.94bc	7.7bc

Abbreviations: CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

TABLE 5 Selection of high-desirable and low-desirable hybrids in terms of mean comparison by Duncan's method.

Traits	Hybrids with high desirability	Hybrids with low desirability	Traits	Hybrids with high desirability	Hybrids with low desirability
DGM	G1,G19,G2	G9,G17,G13	TL	G18,G4,G13	G15,G19,G9
DV10	G6,G3,G1	G11,G17,G13	LACT	G13,G15,G7	G18,G17,G6
DT	G9,G1,G5	G20,G11,G13	NTB	G5,G2,G1	G7,G16,G18
DS	G4,G5,G3	G10,G20,G15	NFS	G3,G9,G6	G12,G18,G10
DP	G1,G5,G4	G11,G20,G13	WTG	G17,G2,G3	G1,G8,G4
DTD	G14,G20,G11	G8,G1,G15	NSPR	G3,G5,G8	G1,G8,G12
DPM	G10,G12,G2	G18,G17,G9	NRE	G4,G5,G6	G19,G2,G18
PH	G20,G3,G17	G10,G2,G7	NCS	G14,G7,G6	G10,G1,G18
EL	G4,G9,G16	G12,G1,G10	CCC	G12,G18,G15	G11,G17,G9
LL	G11,G17,G6	G3,G14,G15	DE	G3,G6,G9	G8,G2,G19
LW	G1,G18,G3	G9,G10,G19	CCD	G12,G7,G16	G1,G18,G19
LS	G11,G1,G19	G7,G3,G4	SD	G6,G4,G14	G18,G19,G8
PL	G12,G9,G14	G1,G18,G10	YLD	G8,G15,G1	G18,G14,G3
POFL	G7,G14,G8	G2,G3,G1	In terms of all traits	G3,G6,G7,G4	G18,G19,G20,G17

Abbreviations: CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

conducted in order to investigate the principal component analysis on 12 corn genotypes, 49.87% of the variance of the total data was justified by the first three components (Magudeeswari et al., 2019). In another research that was conducted to analyze the main components in sweet corn, the first six components accounted for 63.83% of the variance of the total data (Hemavathy, 2020).

3.3 | Graphical analysis

The GGE biplot method was used to check the GT and identify the optimal genotypes in terms of the studied traits. In this diagram, the genotypes that have the greatest distance from the origin of the diagram are connected by lines and form a polygon so that other genotypes are placed inside this polygon (Yan, 2014). Based on the polygon diagram drawn on the data obtained in the experiment, genotypes G1, G5, G6, G3, G9, G7, G11, and G18 have the greatest distance from the origin of the diagram and were identified as desirable hybrids. Genotypes G15 and G8 did not react to changes in traits due to their proximity to the origin of the graph. In each section, specifically, the traits of days until tasseling and days until V10-ten leaf collar in genotype G5, traits of the days until pollination and number of the seeds per row in genotypes G4 and G6, traits of seed depth and ear diameter in genotype G3, traits of the number of seeds per row, seed moisture content, and ear length in G9 and G7 genotypes, plant height trait in G13 genotype, leaf surface trait in G18 genotype, day to germinate maize and peduncle length traits in G2 genotype, and trait of the days until the physiological maturity in G10 genotype had higher performance than other hybrids (Figure 2). Various researchers have used this type of diagram to examine the genotypes evaluated in the experiments (Ansarifard et al., 2020; Mousavi et al., 2021; Omrani et al., 2022; S. Shojaei et al., 2022). In examining the stability diagram of genotypes in terms of studied traits, G3, G14, G9, G6, G4, and G5 hybrids had the most desirability, and G18, G19, G20, and G11 hybrids had the lowest yields in terms of all traits. Also, genotypes G3, G6, G15, G8, and G19 were chosen as hybrids with high stability in terms of traits due to their proximity to the axis of averages in the graph. In this analysis, hybrids G3 and G6 can be selected as genotypes with high performance and stability in terms of traits evaluated in the experiment (Figure 3). According to the diagram of the examination of genotypes, based on the ideal genotype, the linear coordinate is connected from the origin to the mean point and continues to the sides. The best genotype is the one that is close to the positive end of this axis. In this graph, the best point is the center of the concentric circles marked with an arrow, and other genotypes are ranked based on this point. The genotype that has the smallest distance from this point is identified as the superior genotype. The graph of the ideal genotype is drawn based on determining the distance from the hypothetical ideal genotype. This hypothetical ideal genotype is defined based on the most stable and productive genotype (Yan & Kang, 2002). In the evaluation of the diagram of the examination of genotypes based on the ideal genotype, hybrids G3, G6,

TABLE 6 Eigenvalues, proportion, cumulative variance, and decomposition into principal components (PCs) in the examined traits in 20 maize hybrids.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
DGM	−0.10	0.17	0.15	−0.13	−0.06	0.34	0.34	0.19	−0.07	−0.23	0.15	−0.12	−0.42
DV10	−0.17	0.43	0.001	−0.08	−0.11	−0.10	−0.08	0.05	0.16	0.09	0.21	0.10	−0.01
DT	−0.07	0.39	−0.24	−0.03	0.19	−0.21	0.00	0.07	−0.08	0.12	0.02	−0.04	−0.07
DS	−0.10	0.43	0.00	−0.04	0.05	−0.05	−0.02	−0.40	0.04	0.14	0.00	−0.13	0.06
DP	−0.20	0.38	0.01	0.12	0.21	−0.09	0.08	0.01	0.15	0.06	−0.33	−0.04	−0.05
DTD	0.15	−0.04	0.01	−0.21	0.14	−0.06	0.38	−0.06	0.14	0.54	0.21	−0.11	−0.13
DPM	−0.10	0.02	−0.12	0.28	−0.06	0.50	−0.04	−0.17	−0.04	0.11	0.09	−0.40	−0.11
PH	0.16	−0.08	0.25	−0.04	−0.32	0.09	0.17	−0.30	0.01	0.16	−0.13	0.37	−0.23
EL	0.31	0.05	0.25	−0.08	0.02	−0.21	−0.20	0.12	−0.10	−0.11	0.08	−0.19	−0.21
LL	0.001	0.05	0.51	0.11	0.04	0.03	0.001	0.01	−0.09	0.18	0.15	0.12	0.23
LW	−0.10	0.16	0.36	0.16	−0.15	0.13	0.06	−0.02	0.09	−0.27	0.15	−0.17	0.47
LS	−0.09	0.07	0.33	0.15	0.42	0.09	0.16	0.22	−0.18	0.15	0.07	0.16	−0.07
PL	0.01	−0.11	−0.35	0.28	0.03	−0.07	0.41	0.15	−0.17	0.10	0.05	0.27	0.26
POFL	0.29	−0.01	−0.02	0.14	0.11	−0.18	0.31	−0.12	−0.09	−0.24	−0.19	−0.31	−0.16
TL	0.12	0.12	−0.08	−0.17	0.21	−0.14	0.15	−0.21	−0.05	−0.50	0.47	0.25	−0.01
LACT	0.14	0.08	0.01	0.47	−0.17	−0.16	−0.10	0.05	0.21	−0.06	−0.09	0.02	−0.33
NTB	0.03	−0.06	−0.15	−0.21	0.41	0.30	−0.35	−0.09	−0.10	−0.04	−0.12	0.04	0.08
NFS	0.34	0.19	0.06	−0.06	−0.07	0.14	−0.18	−0.15	0.14	0.13	−0.07	0.31	−0.01
WTG	−0.01	−0.09	−0.10	−0.23	−0.08	0.07	0.16	0.21	0.71	−0.05	0.10	−0.10	0.11
NSPR	0.35	0.17	−0.08	0.18	0.07	0.03	−0.11	−0.05	0.15	−0.09	0.05	0.10	0.02
NRE	0.13	0.25	−0.19	−0.05	−0.28	0.15	0.28	−0.20	−0.19	−0.07	−0.17	0.04	0.26
NCS	0.23	0.06	0.19	−0.26	−0.04	−0.25	0.09	0.21	−0.06	0.02	−0.36	−0.24	0.28
CCC	−0.29	0.06	−0.04	0.18	−0.25	−0.20	−0.08	0.24	−0.07	−0.04	0.01	0.19	−0.07
DE	0.30	0.13	−0.17	0.01	−0.07	0.12	−0.15	0.39	−0.02	0.14	0.22	0.01	0.03
CCD	0.28	−0.01	−0.06	0.29	−0.04	−0.07	−0.07	−0.03	−0.09	0.20	0.35	−0.25	0.17
SD	0.16	0.26	−0.06	−0.18	−0.20	0.29	0.01	0.37	−0.25	−0.01	−0.13	0.05	−0.03
YLD	0.17	0.05	0.06	0.27	0.34	0.24	0.14	0.12	0.31	−0.12	−0.24	0.18	0.09
Eigenvalue	4.5	2.74	2.38	2.02	1.72	1.64	1.42	1.33	1.16	1.07	0.89	0.80	0.77
Proportion	0.16	0.10	0.08	0.07	0.064	0.060	0.052	0.049	0.043	0.04	0.033	0.029	0.028
Cumulative	0.16	0.27	0.35	0.43	0.49	0.55	0.61	0.66	0.7	0.74	0.77	0.8	0.83

	PC14	PC15	PC16	PC17	PC18	PC19	PC20	PC21	PC22	PC23	PC24	PC25	PC26	PC27
DGM	0.18	0.34	0.09	−0.21	−0.20	0.05	0.02	0.21	−0.23	−0.02	0.08	0.03	−0.11	0.16
DV10	0.25	−0.21	0.13	−0.15	−0.09	−0.39	0.07	0.05	0.31	0.41	−0.01	−0.27	−0.09	0.06
DT	0.08	0.26	−0.35	0.40	0.01	0.07	0.38	0.08	−0.05	0.02	−0.05	0.17	−0.22	−0.27
DS	−0.22	0.36	0.05	0.02	−0.06	0.21	−0.21	−0.19	−0.01	0.15	−0.05	−0.01	0.43	0.27
DP	0.11	−0.25	0.02	0.02	0.09	−0.02	−0.43	0.15	−0.06	−0.49	0.13	−0.09	−0.19	0.05
DTD	−0.08	−0.22	0.35	−0.01	−0.02	0.09	0.26	−0.22	−0.01	−0.20	−0.12	0.03	−0.11	0.06
DPM	0.06	−0.28	0.07	0.27	0.18	−0.11	−0.12	0.10	0.02	0.22	−0.08	0.36	0.01	−0.04
PH	0.18	0.19	0.03	0.44	0.09	−0.10	−0.10	0.19	0.18	−0.10	−0.15	−0.19	0.06	−0.10
EL	0.01	0.15	0.00	0.04	0.32	−0.09	−0.08	−0.12	0.46	−0.11	0.12	0.30	−0.17	0.33
LL	0.28	−0.22	−0.38	0.01	0.12	0.30	0.05	0.03	−0.26	0.15	−0.10	0.00	−0.07	0.33
LW	−0.21	0.08	0.23	0.31	−0.10	−0.08	0.26	−0.09	0.05	−0.24	0.15	−0.13	−0.15	−0.05
LS	−0.29	0.05	0.06	−0.11	0.33	−0.11	0.01	0.14	0.10	0.12	0.17	−0.06	0.30	−0.34
PL	−0.06	0.17	0.13	0.18	0.04	−0.07	−0.18	0.05	0.03	0.21	0.21	0.04	−0.21	0.39
POFL	0.20	−0.20	−0.14	0.16	0.02	−0.19	0.18	−0.19	−0.13	0.12	0.25	−0.31	0.29	0.08

(Continues)

TABLE 6 (Continued)

	PC14	PC15	PC16	PC17	PC18	PC19	PC20	PC21	PC22	PC23	PC24	PC25	PC26	PC27
TL	0.02	−0.28	0.13	0.15	0.02	0.21	−0.24	0.04	−0.01	0.02	−0.11	0.13	0.03	−0.16
LACT	−0.24	−0.09	0.19	−0.03	0.01	0.52	0.14	0.16	0.06	0.21	0.01	−0.16	−0.16	−0.01
NTB	0.26	0.08	0.35	0.13	0.19	0.21	0.21	0.13	0.03	0.02	0.11	−0.32	−0.05	0.18
NFS	0.01	−0.05	0.06	−0.04	−0.12	−0.08	0.02	−0.12	−0.29	0.09	0.61	0.31	−0.06	−0.12
WTG	0.06	0.12	−0.16	0.09	0.42	0.12	−0.09	0.04	−0.03	0.10	0.15	−0.05	0.12	−0.03
NSPR	−0.18	0.12	0.05	−0.13	0.28	−0.41	0.10	0.12	−0.42	−0.09	−0.44	−0.05	−0.06	0.16
NRE	0.04	−0.10	−0.09	−0.41	0.29	0.17	0.28	0.18	0.27	−0.15	0.03	0.10	0.07	−0.04
NCS	0.07	0.00	0.35	0.08	−0.09	0.03	−0.13	0.34	−0.13	0.29	−0.17	0.20	0.05	−0.13
CCC	0.35	0.01	0.37	0.06	0.24	0.03	0.17	−0.24	−0.20	−0.16	−0.03	0.24	0.36	0.02
DE	−0.07	−0.16	−0.11	0.19	−0.30	0.04	0.01	0.31	0.11	−0.28	0.04	−0.06	0.44	0.19
CCD	0.40	0.29	0.07	−0.20	0.01	0.09	−0.27	−0.05	−0.01	−0.10	0.05	−0.20	−0.07	−0.36
SD	−0.15	−0.09	−0.03	0.13	0.14	0.13	−0.21	−0.51	−0.07	0.10	−0.15	−0.25	−0.15	−0.12
YLD	0.26	0.09	−0.01	−0.06	−0.29	0.04	0.05	−0.27	0.32	0.03	−0.28	0.22	0.08	−0.04
Eigenvalue	0.62	0.61	0.56	0.48	0.39	0.34	0.29	0.25	0.23	0.18	0.15	0.13	0.11	0.06
Proportion	0.023	0.022	0.020	0.017	0.014	0.012	0.010	0.009	0.008	0.006	0.0056	0.005	0.004	0.0002
Cumulative	0.85	0.88	0.9	0.91	0.93	0.94	0.95	0.96	0.97	0.98	0.988	0.993	0.997	1

Abbreviations: CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

G4, G9, G14, and G5 were identified as desirable hybrids and genotypes G18, G19, G20, and G11 were identified as undesirable genotypes. The ranking order of genotypes from the most desirable to the least desirable hybrid is as follows (Figure 4):

$$G3 > G6 > G4 > G9 > G14 > G5 > G16 > G15 > G7 > G8 > G10 > G13 > G2 > G1 > G17 > G12 > G11 > G20 > G19 > G18.$$

The genotypes grouping diagram grouped the hybrids evaluated in the experiment into nine main groups in terms of all traits. The first group includes G18, G19, and G12 genotypes, the second group includes G11, G20, G17, G13, G16, and G8 genotypes, the third group includes G13 and G16 genotypes, and the fourth group includes G7, G16, G8, and G15 genotypes. The fifth group included G9, G14, and G15 genotypes, and the sixth group included G3, G15, and G8 genotypes. The existing genotypes in the second, third, fourth, fifth, and sixth groups were similar in terms of the existing genotypes due to their proximity in reaction to the traits. The seventh group included G6, G4, and G5 genotypes, the eighth group included G10 and G1 genotypes, and the ninth group included G2 hybrid (Figure 5).

In many researches, in order to evaluate the genotypes in terms of the traits measured in experiments in different plants, graphical analysis with GT biplot method has been used among plants, such as wheat (Omrani et al., 2022), maize (Khatibi et al., 2023; S. Shojaei et al., 2023), rice (Semeskandi et al., 2023), sunflower (Ansarifard et al., 2020; S. Shojaei et al., 2023), and rapeseed (Qasemi et al., 2022).

3.4 | Correlation analysis

Based on the evaluation of the results of the correlation coefficient obtained from the experiment (Table 7), the trait days until V10-ten leaf with the traits the day until tasseling and number of the row in ear, the trait the day until tasseling with the traits the days until pollination, the days until the end of pollination, number of tassel branch, number of the row in ear and seed deep, the trait the days until pollination with the traits the days until the end of pollination, number of tassel branch, number of fill seeds, number of the seeds per row, number of the row in ear and seed deep, the days until tassel dries trait with peduncle outside the flag leaf trait, ear length trait with number of fill seeds, weight of 1000-seeds and number of the row in ear traits, leaf length trait with leaf width trait, leaf width trait with tassel length trait, peduncle length trait with cob corn content and cob corn diameter traits, peduncle outside the flag leaf trait with seed moisture content trait, number of fill seeds trait with number of the seeds per row and diameter ear traits, number of the seeds per row trait with

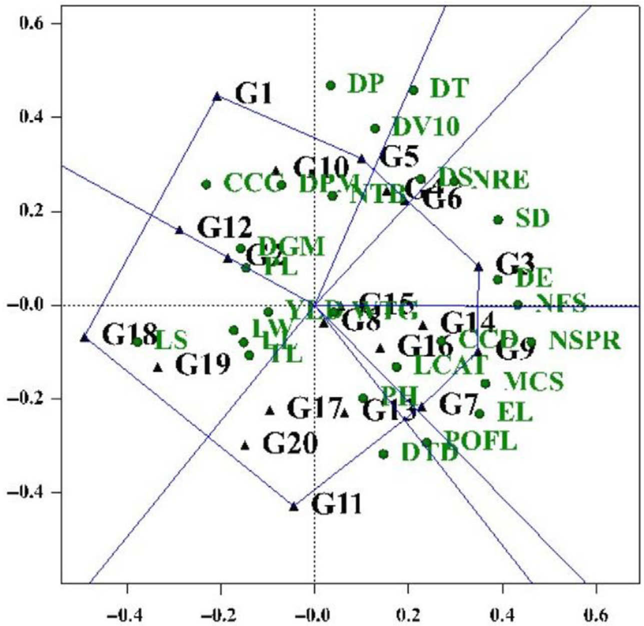

FIGURE 2 Polygon biplot of reaction of maize hybrids to the traits evaluated in the experiment. CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

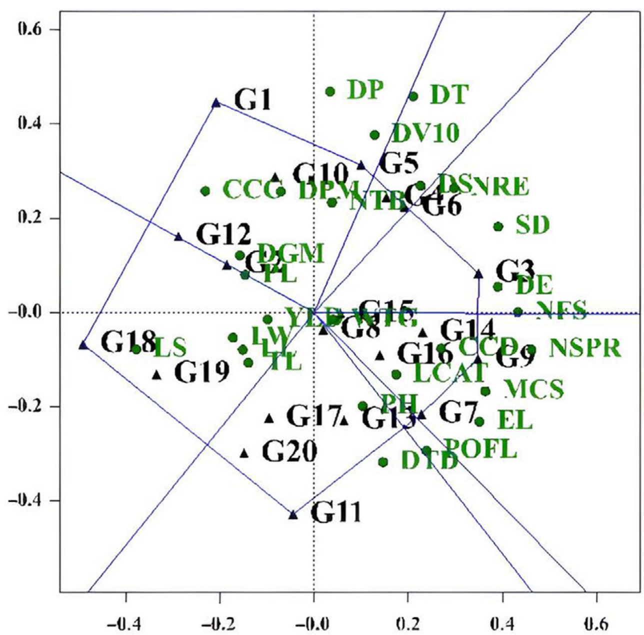

FIGURE 3 Diagram of stability of maize hybrids in terms of traits studied in the experiment.

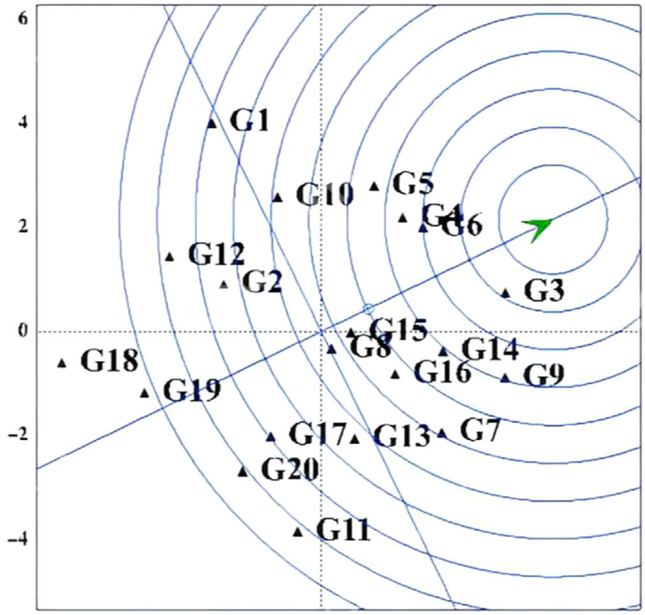

FIGURE 4 Biplot ranking of maize hybrids based on ideal genotype.

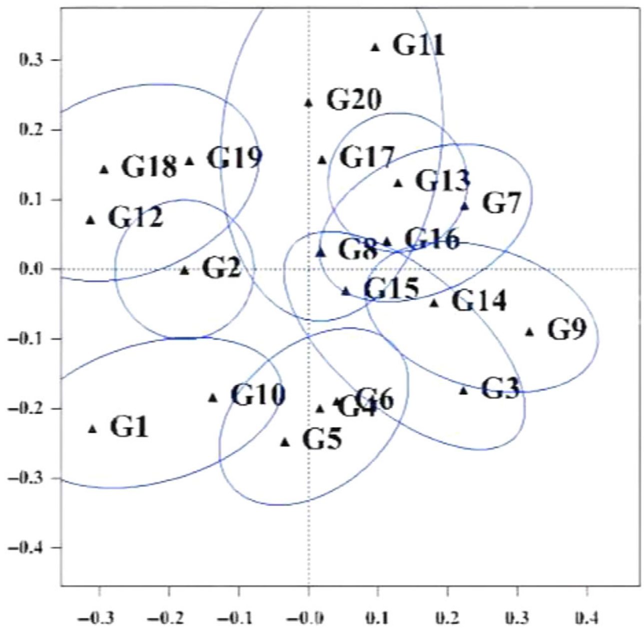

FIGURE 5 Diagram of hybrids grouping in terms of studied traits based on the traits evaluated in the experiment.

seed moisture content, diameter ear and cob corn diameter traits, number of the row in ear trait with diameter ear and seed deep traits, seed moisture content trait with seed deep trait and diameter ear trait with cob corn diameter and seed deep traits had positive and significant correlation. The results obtained from this analysis were consistent with the results obtained in the correlation diagram (Figure 6). Based on the correlation diagram between the traits, the biplot of the cosine angle

TABLE 7 Correlation coefficients of traits evaluated in 20 corn genotypes examined in the experiment.

	DGM	DV10	DT	DS	DP	DTD	DPM	PH	EL	LL	LW	LS	PL	POFL
DV10	0.07													
DT	−0.02	0.63**												
DS	−0.08	0.24	0.57**											
DP	0.17	0.44*	0.63**	0.43*										
DTD	0.07	−0.29	−0.29	0.29	−0.33									
DPM	0.28	0.14	0.26	−0.05	0.1	−0.2								
PH	−0.16	−0.03	−0.25	0.02	−0.13	0.22	−0.6**							
EL	−0.2	0.02	−0.01	0.21	−0.3	0.19	−0.4**	0.15						
LL	−0.47	−0.1	−0.2	0.01	−0.08	−0.2	−0.07	0.08	−0.12					
LW	−0.11	−0.07	−0.33	0.2	−0.04	−0.33	−0.06	0.1	−0.05	0.37**				
LS	0.18	−0.27	−0.31	−0.08	−0.16	0.02	−0.14	−0.13	−0.03	0.33	0.15			
PL	0.003	−0.11	0.09	−0.16	−0.01	0.15	0.3	−0.03	−0.5**	−0.18	−0.08	0.16		
POFL	−0.14	−0.33	−0.17	−0.27	−0.15	0.44*	−0.15	0.03	0.31	−0.09	−0.18	−0.25	0.05	
TL	−0.14	−0.09	−0.2	0.07	−0.24	−0.25	0.01	0.07	0.16	0.22	0.47**	0.12	−0.11	−0.06
LACT	−0.07	−0.27	−0.2	−0.15	−0.27	0.09	0.13	−0.03	0.19	−0.34	−0.02	−0.4*	0.07	0.17
NTB	0.11	0.12	0.4*	0.59**	0.18	−0.17	0.11	−0.33	0.01	0.02	−0.1	0.3	−0.2	−0.44*
NFS	−0.33	0.25	0.29	0.5**	0.17	−0.01	−0.41*	0.3	0.7**	−0.02	−0.08	−0.4*	−0.5**	0.12
WTG	0.012	0.11	−0.08	−0.31	−0.14	−0.1	−0.12	0.05	−0.006	−0.26	−0.12	−0.2	−0.07	−0.11
NSPR	−0.19	0.04	0.12	0.41**	−0.17	0.16	−0.18	0.05	0.62**	−0.27	−0.16	−0.4*	−0.29	0.21
NRE	−0.14	0.4*	0.5**	0.39*	0.33	−0.01	0.32	−0.04	−0.09	−0.05	0.008	−0.5*	0.15	0.23
NCS	−0.01	−0.07	−0.06	0.35	−0.004	0.36	−0.43*	0.29	0.56**	−0.13	−0.04	−0.18	−0.36	0.4*
CCC	0.35	0.34	0.17	−0.21	0.41	−0.17	0.23	−0.11	−0.6**	−0.3	−0.01	0.01	0.56**	−0.27
DE	−0.32	0.37	0.27	−0.07	−0.04	0.14	0.22	0.04	0.26	−0.23	−0.4**	−0.15*	0.01	0.15
CCD	−0.27	−0.15	0.1	0.07	−0.22	0.26	0.35	0.08	0.19	−0.09	−0.13	−0.4*	0.39*	0.3
SD	−0.05	0.34	0.5**	0.4*	0.27	0.1	0.13	0.13	0.11	−0.2	−0.28	−0.4*	0.04	0.23
YLD	−0.03	−0.21	−0.12	−0.04	0.006	−0.22	−0.004	−0.01	−0.23	0.2	0.08	0.2	0.2	0.02
	TL	**LCAT**	**NTB**	**NFS**	**WTG**	**NSPR**	**NRE**	**MCS**	**CCC**	**DE**	**CCD**	**SD**		
DV10														
DT														
DS														
DP														
DTD														
DPM														
PH														
EL														
LL														
LW														
LS														
PL														
POFL														
TL														
LACT	−0.29													
NTB	−0.15	−0.32												
NFS	−0.29	0.17	0.23											
WTG	−0.4*	0.33	−0.13	0.13										
NSPR	−0.12	0.28	0.33	0.65**	0.2									

(Continues)

TABLE 7 (Continued)

	TL	LCAT	NTB	NFS	WTG	NSPR	NRE	MCS	CCC	DE	CCD	SD
NRE	−0.1	0.03	0.06	0.2	−0.09	0.35						
NCS	−0.009	0.14	−0.02	0.6**	−0.19	0.6**	0.17					
CCC	−0.14	0.02	−0.32	−0.5*	0.2	−0.47*	0.06	−0.4*				
DE	−0.25	0.35	−0.14	0.4*	0.23	0.43*	0.37*	0.22	−0.11			
CCD	0.005	0.3	−0.1	0.04	−0.07	0.42*	0.29	0.13	−0.18	0.46*		
SD	−0.37	0.29	−0.006	0.49	−0.006	0.33	0.64**	0.49*	−0.07	0.59**	0.23	
YLD	−0.45**	0.21	0.13	−0.01	0.26	0.01	−0.13	−0.2	0.04	−0.2	0.16	−0.13

Abbreviations: CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PL, peduncle length; PH, plant height; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.
*Significant at 0.05. **Significant at 0.01.

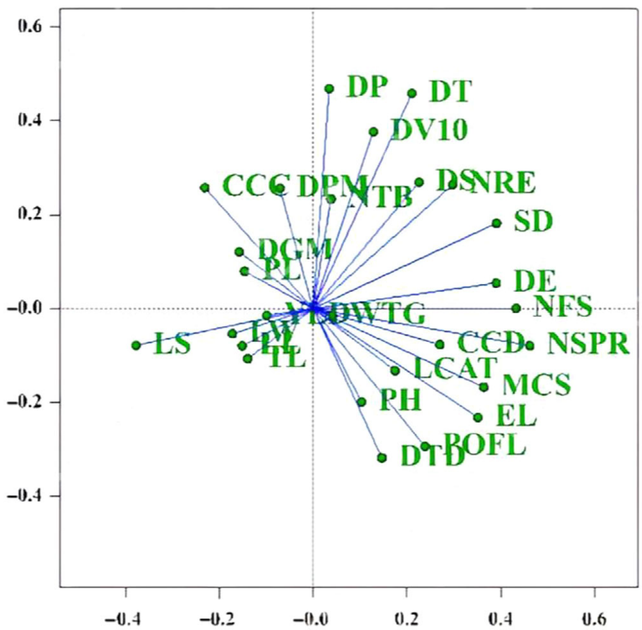

FIGURE 6 Traits correlation diagram in order to determine the relationship between the evaluated traits. CCC, cob corn content; CCD, cob corn diameter; DE, diameter ear; DGM, day to germinate maize; DP, days until the end of pollination; DPM, days until the physiological maturity; DS, days until silking; DT, days until tasseling; DTD, days until tassel dries; DV10, days until V10-ten leaf; EL, ear length; LCAT, length of the central axis of tassel; LL, leaf length; LS, leaf surface; LW, leaf width; MCS, moisture content seeds; NFS, number of fill seeds; NRE, number of the row in ear; NSPR, number of the seeds per row; NTB, number of tassel branch; PH, plant height; PL, peduncle length; POFL, peduncle outside the flag leaf; SD, seed deep; TL, tassel length; WTG, weight of 1000 seeds; YLD, grain yield.

between the vectors of the traits indicates the intensity of the correlation between the traits. If the angle between the vectors is less than 90°, the correlation between the vectors is +1; if the angle between the trait vectors is 90°, the correlation between the trait vectors is 0; and if the angle between the vectors is 180°, it indicates a correlation of −1 (Yan & Kang, 2002). In examining the correlation graph between the traits, the traits of the days until the end of pollination, days until tasseling, days until V10-ten leaf collar, days until the physiological maturity, number of tassel branches, number of the row in ear, seed depth, ear diameter together, traits of seed depth, ear diameter, number of fill seeds, number of seeds per row, 1000-seed weight, cob corn diameter, the length of the central axis of tassel, ear length, peduncle outside the flag leaf, plant height and days until tassel dries together, traits of the length of the central axis of tassel, leaf length, leaf width, leaf surface and grain yield together, and traits of peduncle length, days to germinate maize, cob corn content and days until the physiological maturity together, had a positive correlation. The grain yield trait with ear diameter trait, trait of the days until the physiological maturity with days until tassel dries trait, tassel length trait with seed depth trait, and trait of peduncle length with seed moisture content trait according to the 180° angle between these traits had a negative correlation with each other (Figure 6).

Rafiq et al. (2010) reported that a positive and significant correlation was observed between the weight of 1000 seeds and grain yield. In another study conducted on performance indicators of sweet corn hybrids, in the interpretation of correlation analysis and relationships between traits, a positive correlation of trait ear length with most of the studied traits was reported (Illés et al., 2022).

4 | CONCLUSION

The results obtained from this research, which was conducted to investigate the effect of GT, indicated that these genotypes can be used in breeding programs to increase yield. Based on the analysis of variance, the effect of genotype showed a significant difference in terms of all the traits except for the traits of day till drying, length of the peduncle outside the flag leaf, total length of the corolla axis, number of inoculated seeds, and seed depth. Based on the average comparison, G3, G6, G7, and G4 hybrids were selected as desirable hybrids. Graphic analysis also identified G5, G4, G6, G3, G9, and G14 genotypes as desirable genotypes. Analysis of principal components showed that the first 10 components explained more than 74% of the data variance. In general, G3, G4, and G6 genotypes can be selected as the desired genotypes in terms of the analytical methods.

AUTHOR CONTRIBUTIONS

Seyed Habib Shojaei: Formal analysis; investigation; methodology; project administration; resources; supervision; validation. **Mohammad Reza Bihamta**: Formal analysis; investigation; methodology; supervision. **Seyed Mohammad Nasir Mousavi**: Formal analysis; resources; validation. **Seyed Hamed Qasemi**: Resources; validation. **Mohammad Hossein Bijeh Keshavarzi**: Data curation; software; writing—original draft; writing—review and editing. **Ali Omrani**: Writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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