Cereal Research Communications
https://doi.org/10.1007/s42976-020-00074-5

ORIGINAL PAPER

The plant nutrition impact on the quality and quantity parameters of maize hybrids grain yield based on different statistical methods

Árpád Illés[1] · S. M. Nasir Mousavi[1] · Csaba Bojtor[1] · Janos Nagy[1]

Received: 3 June 2020 / Accepted: 17 August 2020

Abstract

In recent years, producers of agricultural products have increased the use of chemical fertilizers per unit area. The goal of this research was to analyze the interaction of genotype in treatment (NPK fertilizer) on grain yield, protein content, oil content, and the starch content on 13 maize hybrids using analysis by the model of additive and multiplier effects AMMI and to evaluate genotypes, treatments, and their interactions using biplot in Hungary. Treatments include NPK0 (N: 0 kg/ha, P_2O_5:0 kg/ha, K_2O: 0 kg/ha), NPK1 (N: 30 kg/ha, P_2O_5: 23 kg/ha, K_2O: 27 kg/ha), NPK2 (N: 60 kg/ha, P_2O_5: 46 kg/ha, K_2O: 54 kg/ha), NPK3 (N: 90 kg/ha, P_2O_5: 69 kg/ha, K_2O: 81 kg/ha), NPK4 (N: 120 kg/ha, P_2O_5: 92 kg/ha, K_2O: 108 kg/ha), NPK5 (N: 150 kg/ha, P_2O_5: 115 kg/ha, K_2O: 135 kg/ha) in four replications based on complete randomized block design in 2019. The NPK fertilizer effects indicate that the fertilizers are different on yield genotype. AMMI analysis showed that there was a significant difference between genotypes, treatment, and the interaction effect of genotype * treatment at one percent. Besides, the maximum yield had Loupiac and NPK3 on grain yield, Loupiac and NPK2 on oil content, P0023, and NPK3 for starch content, DKC 3/ES4725 (DKC4725) and NPK3 for protein content. Also, GGE biplot analysis indicates that had maximum grain yield in Loupiac, protein content in P9978, oil content in MV Maronetta, and starch content in Sushi.

Keywords NPK fertilizer · AMMI analysis · GGE biplot · Maize

Introduction

There was a rapid increase in population in the world, the need to produce more agricultural products, including important and strategic products such as maize. Therefore, it seems that the best way to achieve this is to increase the production per unit area (Nagy 2006). Maize is one of the most important cereals in supplying energy to humans and livestock. According to the Food and Agriculture Organization, this is the fifth product produced in the world (FAOSTAT 2018). Maize is widely cultivated in many countries for many reasons, such as adaptability to different climatic conditions, relative drought resistance, and high yield. Among cereals, maize has the highest variety of consumption, so that maize, in addition to being consumed as human food, is used as a plant for livestock and used in industrial and processing industries (Hearn 2014). Maize is expected to become more important in the future, as it is considered to be a staple food in large countries and rich countries for the animal protein production (Emam 2011).

The main purpose of a fertilization application is to provide desirable nutrients to the plant during the growing season so that the growth and yield of the plant do not decrease due to lack of food. In this regard, fertilizers have been developed with the aim of precise control of the release of nutrients, as the most advanced technology for providing mineral resources for plants, storing fertilizers, and reducing the environmental pollution (Wu and Liu 2008; Brady and Weil 1999). Plant growth and yield function depending on its genetic capacity and environmental factors such as temperature, humidity, energy radiation, soil structure and porosity, soil reaction, biological factors, nutrient supply (Koocheki and Khajehosseini 2008; Jakson 1967).

The grain yield and protein in maize are highly dependent on fertilizer consumption. Today, however, the use of chemical fertilizers has expanded dramatically as the fastest way to compensate for soil nutrient deficiencies and

✉ Árpád Illés
illes.arpad@agr.unideb.hu

[1] Institute for Land Utilisation, Regional Development and Technology, The University of Debrecen Centre for Agricultural and Food Sciences and Environmental Management, Debrecen, Hungary

Published online: 01 September 2020

high yields, but in many cases, the use of these fertilizers causes environmental pollution and ecological damage and increases production cost (Hearn 2014; Iqbal et al. 2013; Dibaba et al. 2013). Sprouts of kernels are one of the most valuable parts of the maize. Maize contains about 4.5 percent oil, about 85 percent of which is in the sprouts. Each 100 kg can extract approximately 2.2–6.1 kg oil (Thomison et al. 2002). Different farming methods have a direct and indirect effect on the quality of maize oil. Fertilizer application could be an effect on oil and acids in the oil (Ray et al. 2019; Blumenthal et al. 2008; Jellum and Widstrom 1970). There is improving the starch quality, oil content, protein content, and grain yield by international demand because of the nutritional issue (Bilgin et al. 2010).

Reed et al. (1988) and Prasad and Singh (1990), their studies on the effect of nitrogen on maize yield showed that they concluded that yield increases with increasing nitrogen. Nitrogen plays a key role in the production. Production will be decreased if the deficiency in any of the growth stages disrupts the synthesis of substances.

Research has shown that the protein content of maize increases with the amount of nitrogen, and if are used phosphorus and potassium, the content of protein increases (Hera et al. 1988; Cai et al. 2012; Tsai et al. 1983). In many studies has been emphasized due to the positive effect of nitrogen on increasing grain yield, the number of seeds per grain, and grain weight in different maize hybrids. NPK fertilizer increases the leaves number, the length and width of the leaves, and the dryness of the leaves a plant. Also, the results showed that grain and protein yield in maize were affected significantly by the fertilizer treatments and their interaction (Mousavi et al. 2018, 2019; Barker 2012; Gao et al. 2020; Savita et al. 2011; Ahmad Alias et al. 2003; Pepó and Karancsi 2017; Dibaba et al. 2013; Hejazi et al. 2013).

AMMI method justifies a large part of the sum of the squares on the interaction effects and separated the main and interaction effects from each other (Ebdon and Gauch 2002). To analyze the test data, the comparative yield of areas, GGE statistical methods of biplot, AMMI, and the analysis of the main components are used to determine the stability and compatibility of genotypes based on the analysis of individual values (Gauch 2006). The results of the AMMI analysis were useful in guiding breeding programs and help the breeders to choose the environment and genotypes with private and public adaptation (Gauch and Zobel 1988). Generally, the results obtained from AMMI shown in the form of a common graph called a biplot. They show the relationship between genotypes and their interactions with the environment and their interactions (Yan and Rajcan 2002).

Materials and methods

In this research, the experiment was carried out in the Centre for Agricultural Sciences, Institute of Crop Sciences at Látókép by Debrecen University. The site was located in Eastern-Hungary, 15 km from Debrecen in the Hajdúság loess region. In total, 13 maize hybrids were on six fertilizer treatment NPK0 (N: 0 kg/ha, P_2O_5:0 kg/ha, K_2O:0 kg/ha), NPK1 (N: 30 kg/ha, P_2O_5: 23 kg/ha, K_2O: 27 kg/ha), NPK2 (N: 60 kg/ha, P_2O_5: 46 kg/ha, K_2O: 54 kg/ha), NPK3 (N: 90 kg/ha, P_2O_5: 69 kg/ha, K_2O: 81 kg/ha), NPK4 (N: 120 kg/ha, P_2O_5: 92 kg/ha, K_2O: 108 kg/ha), NPK5 (N: 150 kg/ha, P_2O_5: 115 kg/ha, K_2O: 135 kg/ha) in four replications based on complete randomized block design (Table 1). Planting was performed on the April 16, 2019, in a long-term experiment. In total, 72 000 plants/ha were seed number of the hybrids in this experiment. Irrigation was under rainfed conditions and was measured daily rainfall sum. The total rainfall from May until October was 279 mm in 2019 (Fig. 1). Growing maize was favorable conditions in rainfall and temperature.

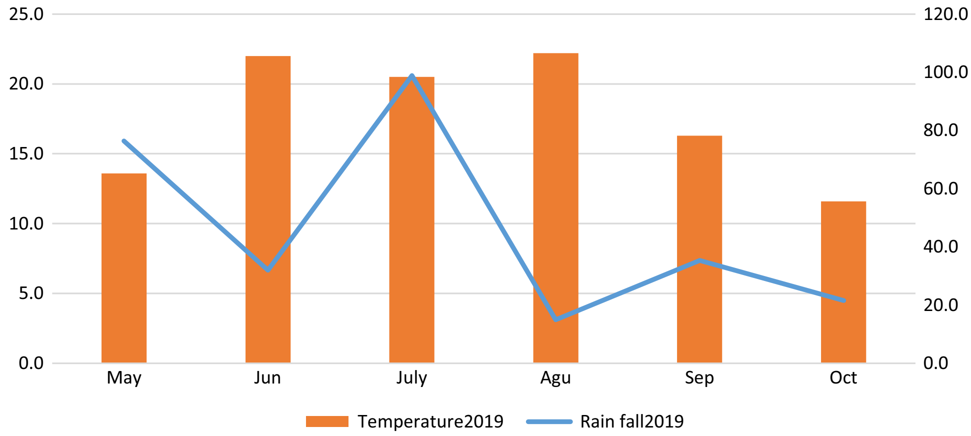
Variance analysis examines the relationship between a dependent variable and one or more independent variables. Independent variables are qualitative, and dependent variables are quantitative. In the variance analysis, research hypotheses can be divided into two forms, which are: (1) there is a significant difference between the variables groups, (2) existence of cause and effect relationship between variables (Farshadfar 2005).

In the GGE biplot graphics method, the selections are based on the graphical analysis of information and data. This method has many capabilities and simplicity in interpreting outputs. To analyze the data, first, the Bartlett test was performed to check the uniformity of the variances and then

Table 1 Hybrid's name

Hybrids number	Hybrids name	FAO number
1.	P0023	420
2.	P9978	420
3.	P9911	450
4.	SY Premeo	400
5.	SY Carioca	470–490
6.	MV Maronetta	350
7.	Sushi	340
8.	Armagnac	490
9.	Loupiac	380
10.	DKC 1/ES4241	320–340
11.	DKC 2/ES4028 (DKC4098)	290–310
12.	DKC 3/ES4725 (DKC4725)	350–370
13.	DKC 4/5092	380–410

Fig. 1 Monthly mean temperature and precipitation in 2019



the compound analysis performed. GGE was based on genotype main effect (G) as well as genotype by environment interaction (GE), which is the only source of diversity in the evaluation of cultivars. Due to the significant interaction of genotype in treatment, the graphical analysis was performed using the GGE biplot method.

$$Y_{ij} - Y_{.j} = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

Y_{ij} is the average among replications for genotype i ($i=1,\ldots,g$) in environment j ($j=1,\ldots,e$); $Y_{.j}$ is the environment average j among all genotypes and replications; $\lambda_1 \xi_{i1} \eta_{j1}$ and $\lambda_2 \xi_{i2} \eta_{j2}$ are PC1 and PC2, respectively; λ_1 and λ_2 are the eigenvalues associated with each PC; ξ_{i1} and ξ_{i2} are the PC's scores in the ith genotype; η_{j1} and η_{j2} are the scores for each PC in the jth environment, and ε_{ij} is the error associated with the model (Yan et al. 2000; Miranda et al. 2009).

Main additive effects and multiple effect analysis (AMMI), an effective method, has to recommend studying the pattern of genotype interaction by the environment (G × E). The AMMI method is a combination of variance analysis and the analysis of the main components. The AMMI method is used generally for three main purposes. The first AMMI method is a diagnostic model. Compared to other methods, this method is more useful in the statistical analysis of comparative experimental yield, because it provides tools for identifying other submodels that are useful for the data under study. Second, the AMMI method is used to clarify the effect of genotype in the environment (treatment). This method identifies to easy the patterns and relationships of genotypes and the environment (Annicchiarico 2002). Third, the AMMI method is used to improve the precision of yield estimation. For example, increasing the precision of yield performance when using an AMMI is equivalent to increasing the number of replication from two to five (Crossa et al. 1990; Zobel et al. 1988).

By reducing the number of replication and increasing the number of treatments in a test, you can reduce costs and improve the efficiency of selecting the best hybrid. This method has been used, especially in hybrid maize programming (Crossa 1990).

One of the most important and new methods that have been the biplot method is based on multivariate models presented in recent years. To draw the biplot, you must use the values obtained from the multivariate models related to the genotype and the environment of the one figure at a time. The multivariate method analysis is introduced to the main components, the new GGE biplot method (Gabriel 1971). Since the environment is an uncontrollable factor, the GGE biplot method uses the genotype change sources and the genotype–environment interaction to achieve reliable results (Yan et al. 2000). GGE biplot method can be used to reliably in the evaluation of different maize genotypes grown in different environments (Kaplan et al. 2017).

Results

Variance analysis

The variance analysis shows that the protein content, grain yield, starch, and oil content were significant in different treatments in the one percent. Therefore, as a result of the treatment, it had a variety of functions. Also, in the genotypes studied, there was a significant difference in one percent and variety in parameters in each genotype. The protein content was a significant interaction between the genotypes in the treatments by one percent. Therefore, the protein yield observed variable in the interaction of the genotypes in treatments (Table 2).

AMMI model was used to analyze the interaction of genotype in treatment and status study of genotypes. The results

Table 2 Variance analysis of grain yield, oil content, protein content, and starch content

Source	*DF*	Adj SS	Adj MS	*F* value	*P* value
Grain yield					
Replication	3	41.921	13.974	7.83	0.000
NPK	5	956.715	191.343	107.23	0.000
Hybrids	12	321.166	26.764	15.00	0.002
NPK*Hybrids	60	114.518	1.909	1.07	0.356
Error	231	412.189	1.784		
Total	311	1846.509			
Oil content					
Replication	3	0.14500	0.04833	2.68	0.057
NPK	5	0.81000	0.16200	9.00	0.000
Hybrids	12	9.49295	0.79108	43.93	0.000
NPK*Hybrids	60	1.40167	0.02336	1.30	0.090
Error	231	4.16000	0.01801		
Total	311	16.00962			
Protein content					
Replication	3	0.4760	0.1587	1.22	0.404
NPK	5	64.6269	12.9254	99.74	0.000
Hybrids	12	66.5203	5.5434	42.78	0.000
NPK*Hybrids	60	17.3539	0.2892	2.23	0.000
Error	231	29.9340	0.1296		
Total	311	178.9112			
Starch content					
Replication	3	0.4804	0.1601	0.24	0.875
NPK	5	38.2625	7.6525	11.69	0.000
Hybrids	12	211.7929	17.6494	26.97	0.000
NPK*Hybrids	60	50.8971	0.8483	1.30	0.091
Error	231	151.1871	0.6545		
Total	311	452.6200			

of the AMMI variance analysis is given (Table 3) for the main additive and multiplicative effects. Variance analysis increased effects on grain yield, percentage of protein, percentage of oil, starch showed that there is a significant difference between genotypes, treatment, and the interaction effect of genotype * treatment at an of one percent. In this large-scale model, the main additive effects for genotype, fertilizer treatment, and interaction genotype * treatment were 0.23, 0.69, and 0.08% of the sum of squares on grain yield, 0.85, 0.05, and 0.08 in oil content, 0.45, 0.44, and 0.12 in protein content, 0.70, 0.13, and 0.17 in starch. The results of the components interaction effect showed that the first component of the interaction effect of the AMMI model was significant at the level of probability of one percent in grain yield, oil percent, protein content, and starch. The results of the components interaction effect showed that 0.56 of variations of the effective interaction of genotype in treatment occurred in grain yield, 0.47 in oil percent, 0.65 in protein content, and 0.60 in starch. Also, the second component of the interaction effect of the AMMI model was significant in five percent on protein content with 0.21 of variation in the effective interaction of genotype in treatment. In other words, using the second AMMI model is very useful in interpreting the results protein (Table 3). The graphical figure applied to investigate the relationships between genotypes in treatment. The study of the AMMI biplot in grain yield showed that hybrids DKC 4/5092, Sushi, DKC 2/ES4028 (DKC4098), and NPK1 treatment have higher interactions and have the most consequential impact on the interaction. SY Carioca, SY Premeo, DKC 1/ES4241, P0023, and Loupiac of hybrids and NPK3 of treatments have low interactions, and due to their higher yield average than the total average, they can consider hybrids with optimal yield. AMMI biplot showed that SY Carioca and DKC 2/ES4028 (DKC4098) hybrids and NPK5 and NPK4 treatments have higher interactions and have the highest impact on the interaction in oil content. Loupiac, Armagnac, SY Premeo, P0023 hybrids, and NPK2 treatment have weak interactions, and due to their higher yield average than the total average, they can consider hybrids with optimal oil content too. SY Carioca Hybrid and NPK0 and NPK1 treatments have higher interactions and have the biggest impact on the interaction on starch content. P0023 and Armagnac hybrids and NPK3 treatment have weak interactions, and due to their higher yield average than the total average, they can be considered hybrids with optimal starch too. P9911, Sushi, and MV Maronetta hybrids and the NPK1 treatment have higher interactions and have the biggest impact on the interaction on protein content. DKC 3/ES4725 (DKC4725), Armagnac, and DKC 4/5092 of hybrids and NPK3 and NPK4 of treatments have low interactions, and due to their higher yield average than the total average, they can be considered hybrids with optimal protein content too (Fig. 2).

Determine the yield of superior hybrids using GGE biplot graphical method

The average yield of the genotype evaluated using the GGE biplot. In general, the figures that are in the positive direction of the horizontal axis have more yield than the negative side of this axis. This figure has shown the Loupiac hybrid maximum yield and the Sushi hybrid minimum yield in grain yield. The average yield of the hybrids is as follows: Sushi < SY Premeo < MV Maronetta < P9978 < P9911 < P0023 < SY Carioca < DKC 1/ES4241 < DKC 2/ES4028 (DKC4098) < DKC 3/ES4725 (DKC4725) < DKC 4/5092 < Armagnac < Loupiac. Also,

Table 3 AMMI variance analysis for main additive effects and multiplication of grain yield, oil content, protein content, and starch content

Source	*df*	SS	MS	*F*	F_prob	Variance explained%
Grain yield						
Total	311	1846.5	5.94	*	*	
Treatments	77	1392.4	18.08	10.20	0.00000	0.75
Genotypes	12	321.2	26.76	15.09	0.00000	0.23
Environments (NPK)	5	956.7	191.34	48.50	0.00000	0.69
Block	18	71.0	3.95	2.22	0.00380	0.04
Interactions	60	114.5	1.91	1.08	0.34597	0.08
IPCA	16	63.7	3.98	2.25	0.00497	0.56
IPCA	14	25.3	1.81	1.02	0.43415	0.22
Residuals	30	25.5	0.85	0.48	0.99086	0.22
Error	216	383.1	1.77	*	*	0.21
Oil content						
Total	311	15.623	0.0502	*	*	
Treatments	77	12.296	0.1597	12.01	0.00000	0.79
Genotypes	12	10.696	0.8913	67.05	0.00000	0.87
Environments (NPK)	5	0.615	0.1230	4.85	0.00031	0.05
Block	18	0.456	0.0253	1.91	0.01674	0.03
Interactions	60	0.985	0.0164	1.23	0.14053	0.08
IPCA	16	0.459	0.0287	2.16	0.00726	0.47
IPCA	14	0.207	0.0148	1.11	0.34624	0.21
Residuals	30	0.318	0.0106	0.80	0.76562	0.32
Error	216	2.872	0.0133	*	*	0.18
Protein content						
Total	311	178.91	0.575	*	*	
Treatments	77	148.50	1.929	16.25	0.00000	0.83
Genotypes	12	66.52	5.543	46.71	0.00000	0.45
Environments (NPK)	5	64.63	12.925	48.72	0.00000	0.44
Block	18	4.77	0.265	2.24	0.00361	0.03
Interactions	60	17.35	0.289	2.44	0.00000	0.12
IPCA	16	11.27	0.704	5.93	0.00000	0.65
IPCA	14	3.59	0.256	2.16	0.01029	0.21
Residuals	30	2.50	0.083	0.70	0.87512	0.14
Error	216	25.63	0.119	*	*	0.14
Starch						
Total	311	452.6	1.455	*	*	
Treatments	77	301.0	3.908	6.21	0.00000	0.67
Genotypes	12	211.8	17.649	28.04	0.00000	0.70
Environments (NPK)	5	38.3	7.652	8.77	0.00000	0.13
Block	18	15.7	0.873	1.39	0.13972	0.03
Interactions	60	50.9	0.848	1.35	0.06407	0.17
IPCA	16	30.5	1.905	3.03	0.00013	0.60
IPCA	14	9.8	0.701	1.11	0.34751	0.19
Residuals	30	10.6	0.353	0.56	0.96938	0.21
Error	216	136.0	0.629	*	*	0.30

Loupiac hybrid had minimum oil content and MV Maronetta had maximum oil content in this study. The average oil content of the hybrids is as follows: Loupiac < DKC 1/ES4241 < P9911 < SY Carioca < Armagnac < DKC 4/5092 < P9978 < DKC 3/ES4725 (DKC4725) < SY Premeo < DKC 2/ES4028 (DKC4098) < Sushi < P0023 < MV Maronetta. GGE biplot shows that SY Premeo hybrid had minimum starch content and Sushi had maximum

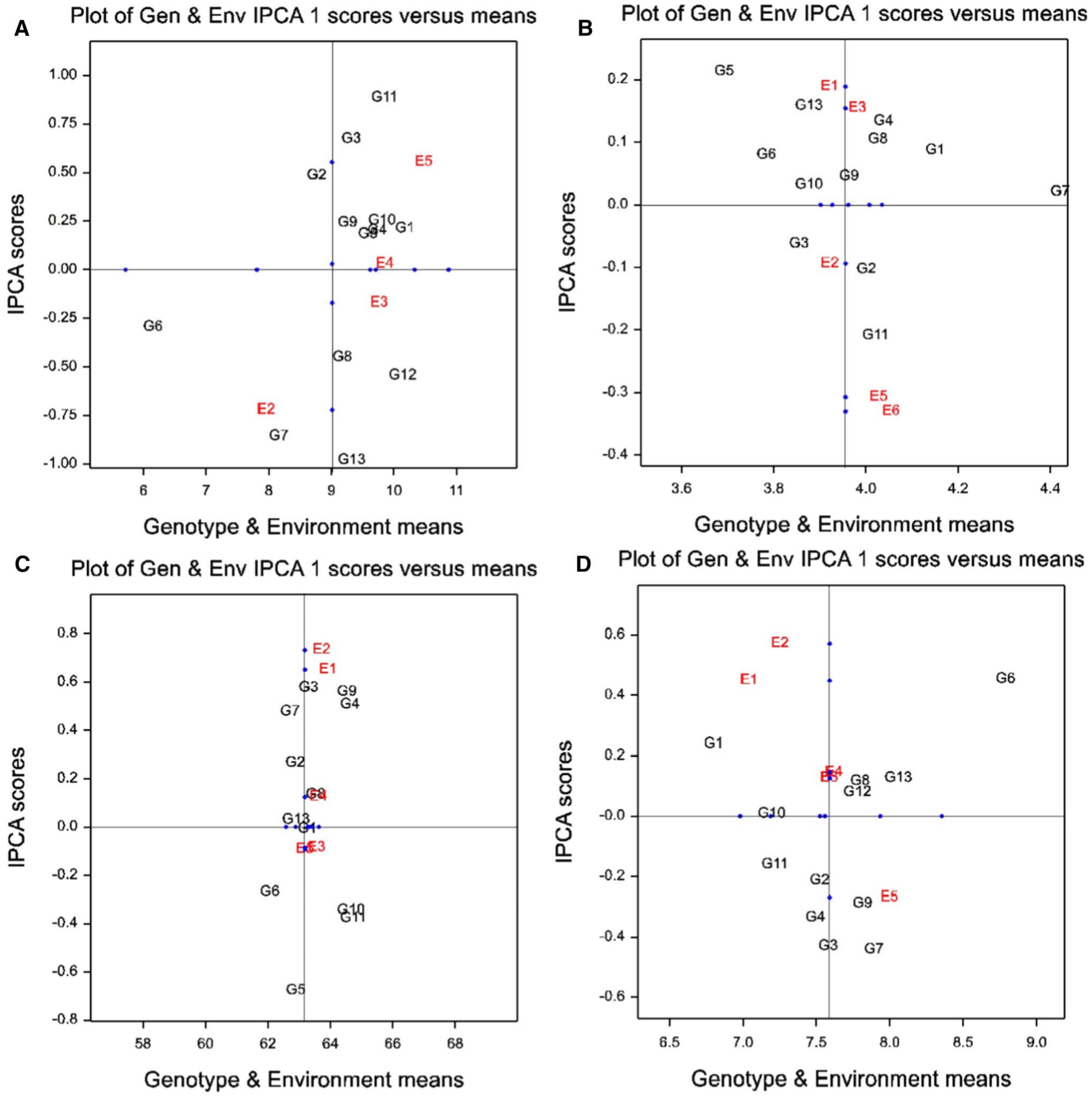


Fig. 2 **a** AMMI biplot of interaction genotype to NPK fertilizer on grain yield, **b** AMMI biplot of interaction genotype to NPK fertilizer on oil content, **c** AMMI biplot of interaction genotype to NPK fertilizer on starch, **d** AMMI biplot of interaction genotype to NPK fertilizer on protein, E1–E6: fertilizer treatments, G1–G13: maize hybrids

starch content of this study. The average starch content of the hybrids is as follows: SY Premeo < Armagnac < P9911 < DKC 1/ES4241 < DKC 2/ES4028 (DKC4098) < P9978 < DKC 3/ES4725 (DKC4725) < MV Maronetta < DKC 4/5092 < P0023 < SY Carioca < Loupiac < Sushi. There are DKC 4/5092 hybrid minimum and FAO 420 hybrid maximum in protein content too. The average protein content of the hybrids is as follows:

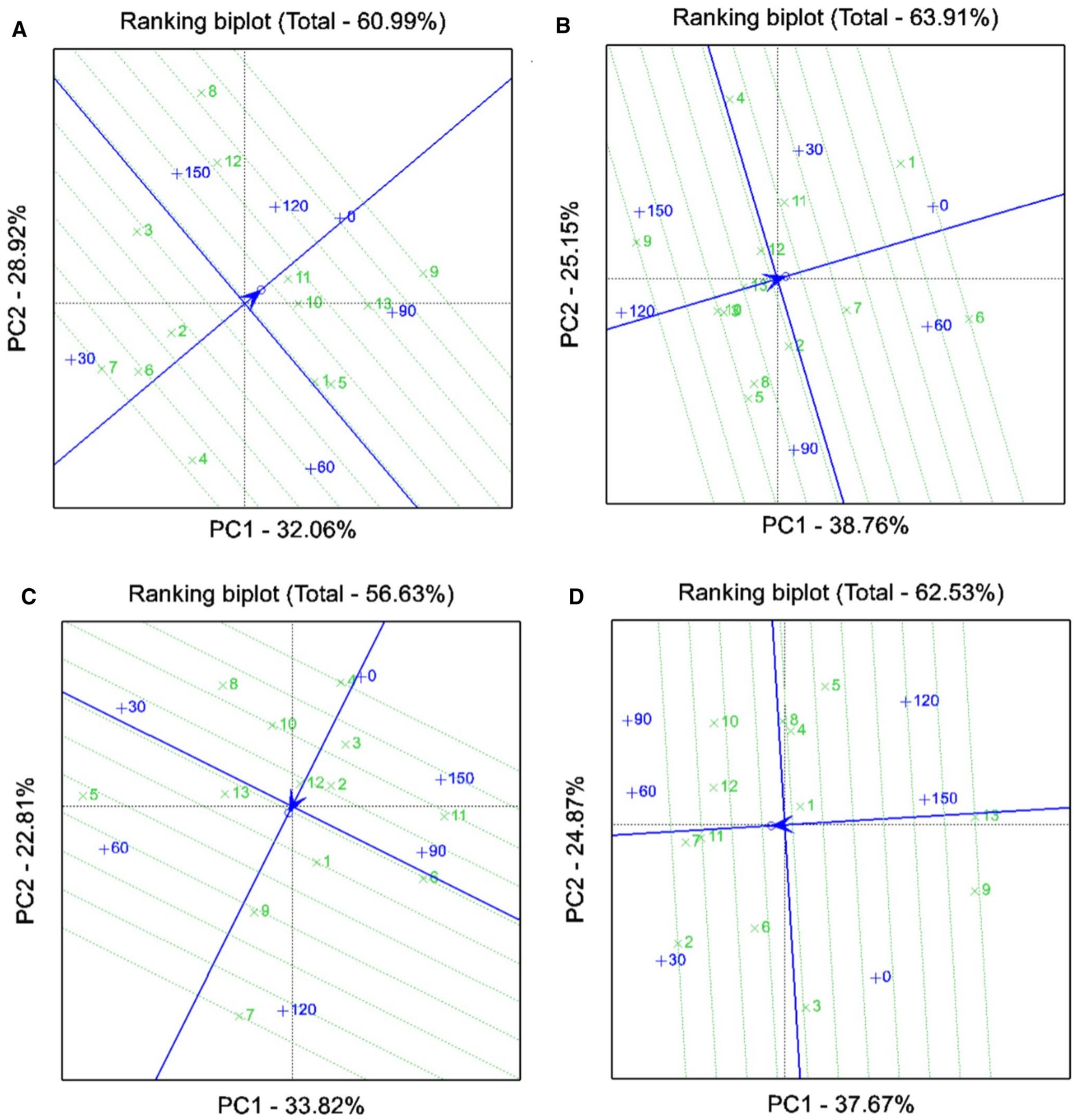


Fig. 3 **a** AMMI biplot of interaction genotype to NPK fertilizer on grain yield, **b** AMMI biplot of interaction genotype to NPK fertilizer on oil content, **c** AMMI biplot of interaction genotype to NPK fertilizer on starch, **d** AMMI biplot of interaction genotype to NPK fertilizer on protein, 0–150: fertilizer treatments, 1–13: maize hybrids

DKC 4/5092 < Loupiac < SY Carioca < P0023 < SY Premeo < P9911 < Armagnac < MV Maronetta < DKC 1/ES4241 < DKC 3/ES4725 (DKC4725) < DKC 2/ES4028 (DKC4098) < Sushi < P9978 (Fig. 3).

Discussion

The goal of this study is obtained to investigate the maximum yield in different treatments (fertilizer) in Hungary. This study explained that Loupiac and Armagnac hybrids had the maximum yield at different treatments on grain yield. Also oil content has the maximum yield on P0023 and MV Maronetta hybrids, the starch content had been on Loupiac and Sushi hybrids, and in protein content, P9978 and Sushi had maximum performance in treatments. In all condition treatments, Loupiac and Sushi hybrids have the maximum yield on all hybrids. The study indicates that NPK3 treatment has maximum grain yield, starch content, and protein content. It showed oil content had the maximum yield on NPK2. Hybrids have the maximum protein content and oil content, and also they have minimum grain yield. Mousavi et al. (2019) showed that FAO380 and FAO410 hybrids have the maximum yield on the NPK4 fertilizer level in Hungary. The NPK fertilizer effects indicate that the fertilizers are different on yield genotype (Nagy 2010). Overall, the results of this study showed that different cultivars of maize have a different yield against nitrogen fertilizer treatments, and Armagnac cultivar had the highest grain yield (Széles et al. 2019). In general, the suitable use of fertilizer can be beneficial for any hybrid, because the amount of nitrogen is out of reach of the plant at the beginning of growth and also pollutes the environment by leaching.

Acknowledgements The research was financed by the Higher Education Institutional Excellence Programme (NKFIH-1150-6/2019) of the Ministry of Innovation and Technology in Hungary, within the framework of the 4th thematic program of the University of Debrecen.

Funding Open Access funding provided by University of Debrecen.

Compliance with ethical standards

Conflict of interest None.

References

Ahmad Alias MU, Ullah E, Warraich EA (2003) Effects of different phosphorus levels on the growth and yield of two cultivars of maize (*Zea mays* L.). Int J Agric Biol 4:632–634

Annicchiarico P (2002) Defining adaptation strategies and yield stability targets in breeding programs. In: Kang MS (ed) Quantitative genetics, genomics, and plant breeding. CABI, Wallingford, pp 365–383. https://doi.org/10.1079/9780851996011.0365

Barker AV (2012) Plant growth in response to phosphorus fertilizers in acidic soil amended with limestone or organic matter. Commun Soil Sci Plant Anal 43(13):1800–1810. https://doi.org/10.1080/00103624.2012.684829

Bilgin O, Orak H, Korkut K, Başer İ, Orak A, Balkan A (2010) Interrelationships among some quality characteristics in dent corn (*Zea mays* L.). Cereal Res Commun 38(2):233–242. https://doi.org/10.1556/CRC.38.2010.2.9

Blumenthal J, Baltensperger D, Cassman KG, Mason S, Pavlista A (2008) Importance and effect of nitrogen on crop quality and health. Agronomy & Horticulture—Faculty Publications. Paper 200; 2008. http://digitalcommons.unl.edu/agronomyfacpub/200. Accessed 24 Jan 2018

Brady NC, Weil RR (1999) The nature and properties of soils. Prentice-Hall Inc., Upper Saddle River

Cai H, Chu Q, Yuan L, Liu J, Chen X, Chen F, Zhang F (2012) Identification of quantitative trait loci for leaf area and chlorophyll content in maize (*Zea mays*) under low nitrogen and low phosphorus supply. Mol Breed 30(1):251–266. https://doi.org/10.1007/s11032-011-9615-5

Crossa J (1990) Statistical analysis of multi-location trials. Adv Agron 44:55–84. https://doi.org/10.1016/S0065-2113(08)60818-4

Crossa J, Gauch W, Zobel RW (1990) Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. Crop Sci 30:493–500. https://doi.org/10.2135/cropsci1990.0011183X003000030003x

Dibaba DH, Hunshal CS, Hiremath SM, Awaknavar JS, Wali MC, Nadagouda BT, Chandrashekar CP (2013) Performance of maize (*Zea mays* L.) hybrids as influenced by different levels of nitrogen, phosphorus, potassium and sulfur application. Karnataka J Agric Sci 26(2):194–199

Ebdon JS, Gauch HG (2002) Additive main effect and multiplicative interaction analysis of national turfgrass performance trials: II. Cultivar recommendations. Crop Sci 42:497–506. https://doi.org/10.2135/cropsci2002.4970

Emam Y (2011) Cereal production, 4th edn. Shiraz University Press, Shiraz

FAOSTAT (2018) Food and agricultural organization. http://www.fao.org/faostat/en/#data/QC/visualize. Retrieved 30 June 2018

Farshadfar A (2005) Multivariate statistical principles and methods. The Razi University of Kermanshah, Kermanshah

Gabriel KR (1971) The biplot graphic display of matrices with application to principal component analysis. Biometrika 58:453–467. https://doi.org/10.1093/biomet/58.3.453

Gao C, El-Sawah AM, Ali DFI, Hamoud YA, Shaghaleh H, Sheteiwy MS (2020) The integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (*Zea mays* L.). Agronomy 10(3):319. https://doi.org/10.3390/agronomy10030319

Gauch HG (2006) Statistical analysis of yield trials by AMMI and GGE. Crop Sci 46:1488–1500. https://doi.org/10.2135/cropsci2005.07-0193

Gauch HG, Zobel RW (1988) Predictive and postdictive success of statistical analysis of yield trials. Theor Appl Genet 76:1–10. https://doi.org/10.1007/BF00288824

Hearn S (2014) 12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition, and Environmental Security. Bangkok, Thailand; 30 October–1 November

Hejazi P, Mousavi SMN, Mostafavi K, Ghomshei MS, Hejazi S, Mousavi SMN (2013) Study on hybrids maize response for drought tolerance index. Adv Environ Biol 7(2):333–338

Hera C, Popescu S, Idriceanu A, Cremenscu G, Ionescu F (1988) Studies on the influence of fertilizers on the protein content and yields of wheat and maize. Analele Institutului de Cercetari Pentru Cereale si Plante Tehnice, Fundulea 56:189–203

Iqbal S, Khan HZ, Akbar N, Zamir MSI, Javeed HMR (2013) Nitrogen management studies in maize (*Zea mays* L.) hybrids.

Cercetari Agron Mold 46(3):39–48. https://doi.org/10.2478/v10298-012-0091-9
Jakson ML (1967) Soil chemical analysis Prentice Hall of India Private Limited. Prentice Hall, New Delhi
Jellum MD, Widstrom NW (1970) Inheritance of stearic acid composition of maize oil. J Agric Food Chem 18:365–370. https://doi.org/10.1021/jf60169a032
Kaplan M, Kokten K, Akcura M (2017) Assessment of genotype × trait × environment interactions of silage maize genotypes through GGE Biplot. Chil J Agric Res 77(3):212–217. https://doi.org/10.4067/S0718-58392017000300212
Koocheki A, Khajehosseini M (2008) Modern agronomy. Publication of Jihad-e-Daneshgahi of Mashhad, Mashhad, pp 147–168
Miranda GV, Souza LV, Guimarães LJM, Namorato H, Oliveira LR, Soares MO (2009) Multivariate analyses of genotype × environment interaction of popcorn. Pesq Agropec Bras Brasília 44(1):45–50. https://doi.org/10.1590/S0100-204X2009000100007
Mousavi SMN, Bodnar KB, Nagy J (2018) Evaluation yield and components yield on three hybrids Maize in Hungary. Eurasia Proc Sci Technol Eng Math 3:51–55
Mousavi SMN, Bodnár KB, Nagy J (2019a) Studying the effects of traits in the genotype of three maize hybrids in Hungary. Acta Agraria Debreceniensis 1:97–101. https://doi.org/10.34101/actaagrar/1/2378
Mousavi SMN, Kith K, Nagy J (2019b) Effect of interaction between traits of different genotype maize in six fertilizer level by GGE biplot analysis in Hungary. Prog Agric Eng Sci 15(1):23–35. https://doi.org/10.1556/446.15.2019.1.2
Nagy J (2006) Maize production. Akadémiai Kiadó, Budapest
Nagy J (2010) Impact of fertilization and irrigation on the correlation between the soil plant analysis development value and yield of maize. Commun Soil Sci Plant Anal 41(11):1293–1305. https://doi.org/10.1080/00103621003759304
Pepó P, Karancsi GL (2017) Effect of fertilization on the NPK uptake of different maize (*Zea mays* L.) genotypes. Cereal Res Commun 45(4):699–710. https://doi.org/10.1556/0806.45.2017.046
Prasad K, Singh P (1990) Response of promising rainfed maize (*Zea Mays* L.) varieties to nitrogen application in northwestern Himalayan region. Indian J Agric Sci 60(7):475–477
Ray K, Banerjee H, Dutta S, Hazra AK, Majumdar K (2019) Macronutrients influence yield and oil quality of hybrid maize (*Zea mays* L.). PLoS ONE. https://doi.org/10.1371/journal.pone.0216939
Reed AJ, Singletary GW, Schussler JR, Williamson DR, Christy AL (1988) Shading effects on dry matter and nitrogen partitioning, kernel number, and yield of maize. Crop Sci 28(5):819–825. https://doi.org/10.2135/cropsci1988.0011183X002800050020x
Savita M, Seema B, Vashist KK (2011) Performance of winter maize (*Zea mays*) hybrid to planting methods and nitrogen levels. Indian J Agric Sci 81(1):50–54
Széles A, Nagy J, Rátonyi T, Harsányi E (2019) Effect of differential fertilization treatments on maize hybrid quality and performance under environmental stress condition in Hungary. Maydica 64(2):14
Thomison PR, Geyer AB, Lotz LD, Siegrist HJ, Dobbels TL (2002) TopCross high-oil corn production. Agron J 94(2):290–299. https://doi.org/10.2134/agronj2002.0290
Tsai CY, Warren HL, Huber DM, Bressan RA (1983) Interactions between the kernel N sink, grain yield, and protein nutritional quality of maize. J Sci Food Agric 34(3):255–263. https://doi.org/10.1002/jsfa.2740340309
Wu L, Liu M (2008) Preparation and properties of chitosan-coated NPK compound fertilizer with controlled-release and water-retention. Carbohydr Polym 72:240–247. https://doi.org/10.1016/j.carbpol.2007.08.020
Yan W, Rajcan I (2002) Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Sci 42:11–20. https://doi.org/10.2135/cropsci2002.1100
Yan W, Hunt LA, Sheng Q, Szlavnics Z (2000) Cultivar evaluation and mega environment investigation based on the GGE biplot. Crop Sci 40(3):597–605. https://doi.org/10.2135/cropsci2000.403597x
Zobel RW, Wright MJ, Gauch HG (1988) Statistical analysis of yield trials. Agron J 80:388–393. https://doi.org/10.2134/agronj1988.00021962008000030002x