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Agronomic Performances and Correlations between Quantitative and Qualitative Indices in High-productive Maize Hybrids (*Zea mays* L.)

Georgieva Rumyana*, Delibaltova Vanya, Kirchev Hristofor

Department of Crop Science, Agricultural University of Plovdiv, Bulgaria

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Abstract The performance and management of agriculture are affected by the climate uncertainty. The right choice of hybrid is among the potential adaptation options in agriculture to climate change. The aim of the present study was to define the productivity of five maize hybrids under non-irrigation and to establish the influence of the factor hybrid in accordance with the specific climatic conditions of the year on the grain yield, as well as on some qualitative and quantitative traits. The field trial was carried out on the territory of the village of Trapishte, region Razgrad with five corn hybrids- DKC4949 (FAO 390); DKC5031 (FAO 430); DKC4590 (FAO 370); P8523 (FAO 260) and P9537 (FAO 390). The following characteristics were reported: grain yield (GY); mass of grain per cob (MGC); cob weight (CW); number of grains per row (NGR); number of rows per cob (NRC); cob length (CL); test weight (TW); 1000 grains weight (TGW) and crude protein (CP). Hybrid DKC5031 is distinguished with the highest values of the crude protein. The largest cob weight and mass of grains per cob by hybrid P8523 were the prerequisite for the formation of the highest grain yields. Grain yield and the crude protein content were negatively related. In contrast to the other indices, the number of rows per cob and the cob length were not affected by the conditions of the year and it could be concluded that these components were influenced only by the hybrid.

Keywords Grain Yield, Maize Hybrids, Correlations

1. Introduction

Maize (*Zea mays* L.) is the most produced cereal crop in the world and the most adapted to different ecosystems [1]. With an annual production of more than 1 billion tons, it constitutes staple foods for large groups of people in Latin America, Africa, and Asia. Maize production has increased because of the strong demand for bioethanol and animal feed. In addition, it serves as a basic raw material for manufacturing of nonfood industrial products, for example biodegradable packaging materials [2].

In the recent years, with the development of the silage techniques, maize has become one of the important silage plants for ruminant animals in the world [3]. Because in the last decades maize has become the main product in the global cereal trade, its stable production is determining for the global food security [4]. An important role in the food security plays the accurate estimation of the regional crop yields [5-8]. Due to its high productive potential and because it serves as raw material for many industries, maize enjoys increased interest from plant breeders. Hybrids with greater stress tolerance and increased plant density are the prerequisite for obtaining higher yields [9, 10]. To determine appropriate plant density and maximize yield, factors as hybrid, environment, and yield goals must be considered. Plant density affects yield components as well as the grain yield [11-13]. Yield components are coherent, possess compensatory effects and are connected directly with the produced amount of grain. First order yield components as number of ears m^{-2} (or ears $plant^{-1}$), kernels ear^{-1}, and kernel weight have a direct effect on final yield as well as indirect effects through later developing yield components [14]. Rows ear^{-1}, ear length, kernels $rows^{-1}$, and ear circumference are considered as second order components, because they indirectly influence the yield through their impact on primary components. The growth and development of the maize plant, as well as the intensity of photosynthesis affect the grain yield. Some authors stated that the yield is a result of the interaction of genotype, management, and environmental factors [15,16].

Because of the global warming and extreme weather events, corn production experiences losses. Timely estimation of the yield can enable better track of its reaction to environmental stress [17] and facilitate the adaptation of the cropping systems for sustainable agriculture [18]. In the recent years, maize cropping in Bulgaria has been threatened due to observed trends for drought aggravation during the vegetation [19], which is associated with decreases in the average yields. The yield variation of rainfed maize is great, due to inter-annual and spatial climatic variability during the vegetation [19]. The right choice of hybrid is among the most important management practices to achieve higher grain yield. To identify the most suitable hybrid for each cultivation area the newly hybrids of maize must be studied in different cultivation conditions [20]. This enables the farmer to select the correct hybrid based on knowledge about the yielding capacity in the specific soil and climatic conditions [20]. The aim of the present study is to define the productivity of five maize hybrids under non-irrigation and to establish the influence of the factor hybrid in accordance with the specific climatic conditions of the year on the grain yield, as well as on some qualitative and quantitative indices.

2. Materials and Methods

In the period 2017-2019 on the territory of the village of Trapishte, region Razgrad (43.37723 ° N latitude 26.536297 ° E longitude), North-Eastern Bulgaria a field experiment was set with five corn hybrids- DKC4949 (FAO 390); DKC5031 (FAO 430); DKC4590 (FAO 370); P8523 (FAO 260) and P9537 (FAO 390). The trial was arranged according to the randomized complete block design in four replications with a plot size of 25 m^2, after wheat as a predecessor. The following characteristics were reported: grain yield (GY); mass of grain per cob (MGP); cob weight (CW); number of grains per row (NGR); number of rows per cob (NRC); cob length (CL); test weight (TW); 1000 grains weight (TGW) and crude protein (CP).

Soil cultivation included primary tillage (8-10 cm) in August after the harvest of the predecessor, followed by plowing at a depth of 28-30 cm in October and two pre sowing cultivations in March and April. The sowing was carried out annually in the period 10-20 April at row spacing 70 cm. Weeds were controlled with the herbicide Spectrum at the dose of 1.3 l ha^{-1}, applied after sowing, before emergence of the crop against grass and some broad-leaved weeds. After formation of 5-6 leaves, they were applied Cambio (2 l ha^{-1}) against broad-leaved weeds and Kelvin Top (1.25 l ha^{-1}) against grass weeds. During the vegetation the inter rows were cultivated twice.

According to the classification of FAO the soil cover in the region is represented by 4th soil types: *Chernozems*, *Phaeozems*, *Fluvisols*, *Anthrosols*, of which 14 soil differences are fixed in total. About 90% of the land area is occupied by *Chernozems* differences and less than 10% of all other soils. The soil in the area is quite loamy, with physical clay reaching 50%. Chemical analysis showed the presence of a significant amount of carbonates, and neutral to an alkaline reaction- pH of 7-7.2. The humus content was high 5-6%. The total stock of nitrogen was 42-46 mg in 1000 g of soil /by Gurov/, with phosphorus 0.3-0.9 in 1000 g of soil / Egner and Rheen / and potassium 22-25 g in 1000 g of soil. The presence of nitrate nitrogen in amount of 9.9 mg kg^{-1} gave good physical and mechanical properties to the soil. The humic content gradually decreased along the soil horizons. The amount of nitrogen, phosphorus and potassium was significant, but their absorbable forms were few. The addition of fertilizers improved the soil nutritional regime. The application of the phosphorus fertilizer took place before plowing at a rate of 50 kg ha^{-1} triple superphosphate and the nitrogen fertilizer was applied with the last pre-sowing soil cultivation at a rate of 30 kg ha^{-1} ammonium nitrate.

Temperatures and precipitation, as well as their combination and distribution during the vegetation influenced maize growth, development, and productivity. For the study period these factors differ in the amount of precipitation, while the average monthly temperatures do not distinguish significantly from those of the multiannual period (Table 1). In the second year of the experiment (2018), the amount of precipitation in the April-September period was 259.5 mm, which is with 84.5 mm lower than the multiannual period (344.0 mm). Moreover, the rainfall was too unevenly distributed. The significant amount of precipitation in the period April - June (166.1 mm) was followed by a drought period. The lack of precipitation, combined with high temperatures, negatively affected the growth processes and productive capabilities of the maize plants. In 2017, the amount of rainfall during the vegetation was with 60.4 mm less than the multi-year period and with 24.1 mm more than in 2018. The last year of the study (2019) was the most favorable in climatic terms and distinguished with the higher amount of precipitation (331.9 mm). The good moisture supply and the uniform distribution of rainfall from the beginning of the vegetation to the beginning of ripening had a beneficial effect on the growth and development of corn plants.

Table 1. Climate conditions during maize vegetation

Year	Temperature (^{0}C)						
	IV	V	VI	VII	VIII	IX	X
2017	10.2	15.6	20.9	22.5	23.1	19.2	11.2
2018	15.5	18.0	20.4	21.5	23.3	18.4	13.4
2019	10.2	16.0	21.2	21.8	23.4	19.3	14.7
long-term average	10.7	15.8	19.2	20.9	20.4	16.8	11.2
Precipitation (mm)							
2017	45.7	71.2	52.9	59.4	47.3	7.1	111
2018	16.5	36.8	112.8	50.1	15.9	28.4	17.9
2019	10.2	66.5	101.2	53.7	40.2	6.7	30.1
long-term average	51	72	74	59	47	41	34

The experimental data were processed according to the ANOVA analysis of variance with significance level of 0.05. In order to calculate the relationships between the investigated traits, a correlation analysis and PCA biplot were used. The products SPSS and XLSTAT Version 2016.02 have been used for the statistical data processing.

3. Results and Discussion

The impact of both variables - hybrid and year on the yield, as well as on the other qualitative and quantitative components are presented in Table 2. Regarding the grain yield on average for the period by the hybrids DKC5031 and DKC4590 has been reported the lowest values of 9.3 t ha^{-1} and 9.4 t ha^{-1} respectively, as the differences were statistically not significant and both hybrids have been placed in the same group. Hybrids DKC4949 and P9537 were statistically proven more productive, but the differences between them were very small, that's why they were situated also in one statistical group. For the tested period hybrid P8523 was distinguished with the highest values of the grain yield (11.4 t ha^{-1}), which placed this hybrid in a separate statistical group. The values of the indicator are varying depending on the year. The uneven distribution of rainfall in 2017 and especially their shortage during the stages inflorescence emergency and flowering are the reason for the reported lower grain, as the differences with the second and the third year are significant and proven. In 2018 and 2019 due to the better conditions the values of the indicator increased, but the differences between both years remain unproven. Branković-Radojĉić et al. [21] reported significant grain yield variation due to the differences in average monthly temperatures and precipitation amount and distribution. According to Oyekunle et al. [22] the fact that in certain regions the different genotypes that express different performance could be used to achieve maximum productivity. Liu et al. [23] reported significant correlation between maize grain yield and the amount of precipitation, as the highest values were reported when precipitation from sowing to harvest was between 506 and 537 mm depending on the plant density. The same authors found out a significant interaction effect of year and hybrid type on 1000 kernels weight and maize grain. Asare et al. [24] observed also dependence of the grain yield on the amount of precipitation.

An important indicator on which the yield of maize depends is the mass of grains in a cob [25]. The factors influencing the values of this indicator are the technology of cultivation, the weather conditions, as well as the genetics of the hybrid [25-28]. Differences in the climatic conditions during the years of the experiment are one of the reasons for the formation of grain with different mass. Mass of the grain per cob varied from 222 g by hybrid DKC5031 to 283 g by hybrid P8523 and the differences were big enough to place them in separate groups. The values of DKC 4949 were very closed to those of P8523 and the differences between both hybrids remain unproven. With difference of only 7 g (in favour of hybrid DKC4590) the hybrids DKC4590 and P9537 were placed in one group. The three years proven influence the mass of the grain per cob by all hybrids. In line with the observations for the grain yield, the lowest values of mass of the grain per cob are reported in the first year, when the conditions were not so favourable. Ali et al. [25] observed differences in grain weight per cob with values varying from 163.23g to 133.97 g depending on the hybrid. According to the same author, an increase in the grain yield was due to higher values of indices like- number of cobs per plant, number of rows per cob, number of grains per cob, grain weight per cob and 1000 kernels weight.

Table 2. Differences between the qualitative and quantitative components

Variables	GY	MGC	CW	NGR	NRC	CL	TW	TGW	CP
	Hybrids								
DKC4949	10.3[b]	268[c]	352[c]	39.5[c]	17.3[c]	22.3[c]	69.9[a]	346[a]	11.3[b]
DKC5031	9.3[a]	222[a]	255[a]	38.0[a]	14.7[a]	20.3[a]	67.0[a]	367[b]	12.1[c]
DKC4590	9.4[a]	245[b]	308[b]	38.7[b]	17.9[c]	22.1[c]	73.2[b]	360[b]	11.7[b]
P9537	10.5[b]	238[b]	312[b]	38.2[a]	15.4[a]	20.8[a]	72.0[b]	368[b]	10.6[a]
P8523	11.4[c]	283[c]	378[c]	39.2[c]	16.4[b]	21.6[b]	76.9[c]	375[c]	10.2[a]
	Years								
2017	9.7[a]	237[a]	311[a]	38.0[a]	16.0[a]	21.1[a]	65.7[a]	355.2[a]	11.5[b]
2018	10.1[b]	253[b]	320[b]	38.6[b]	16.3[a]	21.4[a]	74.0[b]	363.4[a]	11.0[b]
2019	10.7[b]	264[c]	332[c]	39.5[c]	16.8[a]	21.8[a]	75.1[b]	371.4[b]	10.2[a]
LSD 5%	*0.51*	*17.2*	*13.3*	*0.95*	*1.32*	*1.21*	*2.25*	*8.21*	*0.82*

*Values with the same letters do not differ significantly

The results of the cob weight follow the same tendency and the heaviest cobs with average weight of 332 g were formed in 2019. Both mass of the grain per cob and cob weight are correlated with the grain yield and for this reason by the most productive hybrid P8523 the values of those parameters are the highest. The difference in the mass of the cob of P8523 and DKC4949 is very small and statistically not significant. The values of the indicator by the estimated as less productive hybrid DKC5031 differ significantly from those of the other hybrids and placed this hybrid in a separated group. The highest average number of grains per row of 39.5 was observed by hybrid DKC4949, but the differences with hybrid P8523 are not significant and both are placed in the same group. With average value of 38.7 grains per row hybrid DKC4590 differs significantly from the other and is situated in separated group. The lowest number of grains per row was reported by the hybrids DKC5031 and P9537, as the differences between their values are not proven. In contrast to the other indices, the number of rows per cob and the length of the cob were not affected by the conditions of the year and it could be concluded that these components were influenced only by the hybrid.

The biggest number of rows per cob was observed by the hybrid DKC4590, and DKC4949 distinguished with the longest cobs. Our observations agree with the observation of Ali et al. [25] and Gul et al. [26] who reported a significant variation in cob length in various maize hybrids.

The test weight is influenced by both the genetics of the hybrids and the climatic conditions of the year. In the first year of the experiment (2017) during grain filling and maturity, the small amount of rainfall had a less favorable effect on the indicator compared to 2018 and 2019 years. The lowest values of 67 kg and 69.9 kg were reported by the hybrids DKC5031 and DKC4949 respectively. The values of the indicator are significant higher by the hybrids DKC4590 and P9537, as the smaller differences place the hybrids in one group. Hybrid P8523 differs significant from the others with the highest values of 76.9 kg. According to Delibaltova et al. [27] the most significant influence on the variation of the test weight has the hybrid and the conditions of the year, as the interaction between the two factors is less pronounced.

1000 grains weight is an indicator of the yield quality. Its values are influenced by environmental conditions, cultivation technology and genetics of the hybrids. According to Ali et al. [25] the 1000 grains weight is genetically determined factor, and the selection of the suitable hybrid can manage the influence of the environment. The largest mass per 1000 grains was observed in the third year, because of the optimal weather conditions. With a value of 375 g hybrid P8523 distinguished significantly from the other hybrids. Delibaltova et al. [27] found out that the 1000 grains weight is influenced by both the hybrid and the climatic conditions of the year, as well as by the interaction between them.

In contrast to the previous indicators, the crude protein content followed a reverse trend and the lowest values were recorded during the year with the highest amount of precipitation (2019). Due to dilution the increased amount of precipitation resulted in higher grain yields, but lower crude protein values [29-31]. Higher starch content in the grain could also be a possible reason for lower protein content [32]. Xu et al. [33] stated that the application of lower irrigation advertises the transport of nitrogen and forces the accumulation of protein. By the most productive hybrid P8523 was recorded the lowest value of the crude protein - 10.2 %, as the difference with hybrid P9537 is very small and not proven. With values of 11.3 % and 11.7 % hybrids DKC4949 and DKC4590 differ significantly from hybrids P8523 and P9537, but not from each other. Hybrid DKS5031 proven contained the highest amount of crude protein (12.1%) but was less productive. To achieve sustainable agriculture and to meet the producer needs, it is important to consider both quantity and quality of the grain. Proper land management can provide not only high yields, but also quality production [34].

The performed correlation analysis (Table 3) between the qualitative and quantitative components indicated a very strong correlation (*r>0.9*) between the following indicators: cob weight and mass of grain per cob; length of the cob and number of rows per cob. Strong to mean relation *(r>0.8; r>0.7;r > 0.6)* exist between the indices: cob weight and grain yield; mass of grain per cob and grain yield; number of grains per row and mass of grain per cob; cob length and number of grains per row; cob length and mass of grain per cob; number of grains per row and cob weight; test weight and grain yield; test weight and mass of the grain per cob; cob length and cob weight; number of rows per cob and number of grains per row. According to the number of grains per row and grain yield (*r=0.599*); number of rows per cob and mass of the grain per cob (*r=0.548*); number of rows per cob and cob weight (*r=0.533*); test weight and cob weight (*r=0.558*); test weight and number of grains per row (*r=0.594*); 1000 grains weight and test weight (*r=0.562*) a positive and moderate correlation was found. Devasree et al. [28] also stated a highly significant and strong relation between cob weight and grain yield. This is in line with the observation of Soumya and Kamatar [35]. A positive relation and dependency of yield on the cob length, number of rows per cob and 1000 grains weight was confirmed by Synrem et al. [36]; Pandey et al. [37]; Reddy and Jabeen [38]; Devasree et al. [28]. Negative correlation was observed between the crude protein and all the other variables. The same tendency was reported also from Werle et al. [39].

The PCA results showed that 90.39% of the total variability was explained by the two principal components (Figure 1). The PC1 explained 60.86% of the variability and mainly accounted for the number of grains per row, cob length, number of rows per cob and 1000 grains weight. The angle between the vectors 1000 grains weight and grains per row, cob length, number of rows per cob is greater than 900 C, because of the observed negative relation among these traits. The maximum values of those parameters have been recorded by the hybrids DKC 4949 and DKC 4590 and for this reason the hybrids are located near the vectors of those indices. The PC2 accounted for additional 29.53% of the total variability among the traits and appeared to be related with the grain yield, test weight, cob weight, mass of the grains per cob and the crude protein content. The indices test weight, cob weight and mass of the grain per cob have a strong correlation with yield rank, which is evident from the location of their vectors relative to that of grain yield. The acute angles observed between these vectors are strong enough evidence for the proven relationship with the grain yield. By hybrid P8523 was recorded the highest values of the grain yield, test weight, cob weight and mass of the grains per cob, which explains the location of the hybrid near to the projections of this traits. The straight angle between the crude protein and grain yield, as well as the reflex angles with the other indices presented the negative relation between the traits.

Table 3. Correlation matrix (Pearson), (n=30)

Variables	GY	MGC	CW	NGR	NRC	CL	TW	TGW	CP
GY	**1**								
MGC	**0.804**	**1**							
MC	**0.834**	**0.942**	**1**						
NGR	**0.599**	**0.860**	**0.719**	**1**					
NRC	0.145	**0.548**	**0.533**	**0.628**	**1**				
LC	0.328	**0.725**	**0.685**	**0.808**	**0.950**	**1**			
TW	**0.644**	**0.680**	**0.558**	**0.594**	0.384	**0.462**	**1**		
TGW	**0.457**	0.161	0.059	0.049	-0.331	-0.319	**0.562**	**1**	
GP	**-0.924**	**-0.715**	**-0.813**	**-0.468**	-0.188	-0.331	**-0.658**	-0.382	**1**

*Values in bold are different from 0 with a significance level alpha=0,05

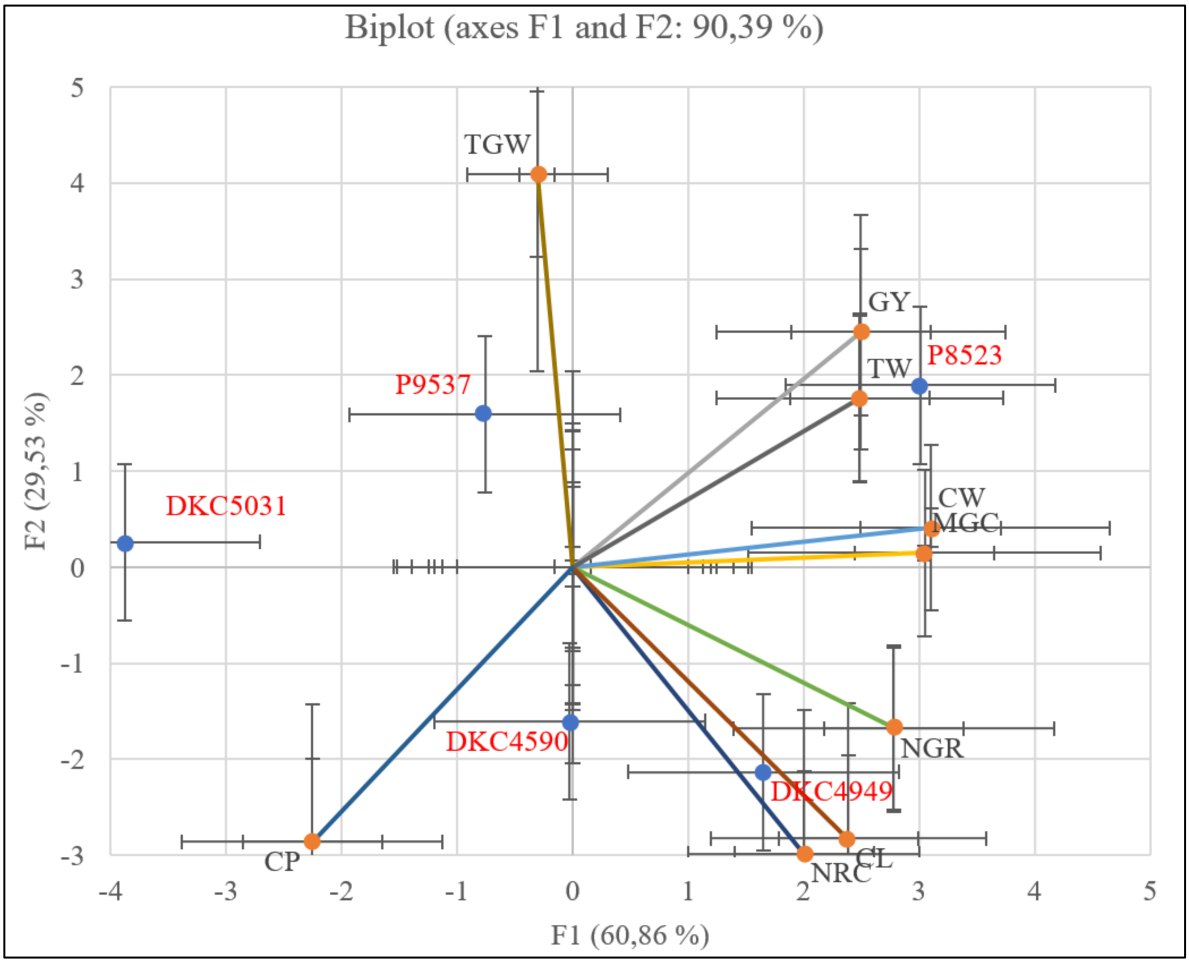

Figure 1. Spatial grouping of the hybrids and qualitative and quantitative components through Biplot of Principal Component analysis (PCA).

4. Conclusions

The productivity of the tested hybrids has been determined by the genetics of the hybrids, as well as by the weather conditions of the year. In contrast to the grain yield and the other qualitative and quantitative parameters, the crude protein content was higher during the years with the smaller amount of rainfalls. Hybrid DKC5031 distinguished with the highest values of the crude protein-12.1%. The largest cob weight and mass of grains per cob by hybrid P8523 were the prerequisite for the formation of the highest grain yields. Grain yield and the crude protein content were negatively related. The values of the indicators 1000 grains weight and test weight were highest by the hybrid P8523. Regarding the quality of the production hybrid DKC5031 distinguished with the highest values of crude protein, but for the right choice of variety both factors – quality and quantity of the production must be taken into account. In this connection, for the region of Razgrad we could recommend hybrid DKC4949, where the productivity and the quality are balanced under the contrast conditions of the studied years.

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