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# Performance Evaluation of Maize Hybrids (*Zea mays* L.) for Quantitative and Qualitative Traits in the Region of North-East Bulgaria

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## ABSTRACT

**Maize (*Zea mays* L.) is one of the most important crops in Bulgaria in terms of both cultivated area and production. The selection of an appropriate hybrid, considering its genetic potential, is crucial for achieving high grain yield and quality. The objective of this investigation was to evaluate grain yield, yield components, and selected quality traits of five maize hybrids cultivated in Northeastern Bulgaria. A field experiment was carried out in the Targovishte region during the period 2021-2023 with five maize hybrids: P 9241 (FAO 370), P 9610 (FAO 375), DKC 4670 (FAO 380), ES METHOD (FAO 380), and KNEJA-435 (FAO 400). The following characteristics were evaluated: grain yield, grain weight per cob, cob weight, number of grains per row, number of rows per cob, cob length, 1000-grain weight, test weight, and crude protein content. The results showed that maize hybrids' production potential is determined by their genetics and the year's climatic conditions, especially precipitation variability. During the years of study, the highest grain yield was obtained from DKC 4670, followed by P 9610, while the lowest yield was recorded for KNEJA-435. The hybrid P 9610 yielded the highest 1000-grain weight and test weight. The hybrid KNEJA-435 stood out due to its high crude protein content. Out of the studied maize hybrids for the region of Targovishte, the hybrid DKC 4670 is recommended due to its balanced productivity and quality under the contrasting conditions of the studied years, despite showing lower stability in relation to genotype × environment interaction. The hybrid P 9610 was the most stable under different environmental conditions. The strongest positive influence on grain yield was exerted by grain mass per cob and cob length, while a negative influence was observed between grain yield and crude protein content.**

**Keywords:** maize hybrids, grain yield, protein content, yield stability, correlation analysis.

## INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in the world. It is used as a raw material for industries, as well as a source of food for humans and fodder for animals (Kunwar and Shrestha, 2014; Dhakal et al., 2017; Güneş and Öner, 2019; Yadav et al., 2025). The productive potential of maize is manifested when an optimal combination of various factors is attained, including the hybrid, agroecological and climatic conditions, and the applied agricultural technology employed (Mitkov et al., 2019; Rizzo et al., 2022; Akhtar et al., 2023; Gao et al., 2023; Rankova et al., 2023; Paliwal and Smith, 2024). Under current climate change conditions, increased variability in precipitation and temperature leads to significant fluctuations in maize productivity, particularly in semi-arid regions of Eastern and South-Eastern Europe. In Romania, research has shown that soil management practices and climatic variability have a direct influence on cereal yield and quality, mainly through their effects on soil water availability and nutrient dynamics (Cociu and Alionte, 2017). Similar findings were reported by Dragomir et al. (2022), who emphasized that climate-driven instability combined with suboptimal agronomic practices can significantly limit maize productivity and competitiveness in the Eastern European context. Moreover, Horhocea et al. (2024) highlighted that genotype × environment interactions remain a key limiting factor for yield stability in maize under contrasting pedoclimatic conditions in Romania and neighboring regions. Among these factors, the choice of hybrid, with its specific genetic

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potential, is one of the most important management practices for achieving higher grain yield. (Kolisnyk et al., 2020; Habiba et al., 2022; Menkir et al., 2022; Mosisa et al., 2023; Sedhom et al., 2024; Tarekegne et al., 2024). The primary objective of maize breeders is to develop novel commercial genotypes that can acclimatize to diverse environmental circumstances (Malenica et al., 2021; Prasanna et al., 2021; Dossa et al., 2023; Ahmad et al., 2024). The use of new hybrids is needed to maintain the stability of maize production (Syahruddin et al., 2020; Hidayatullah et al., 2025).

Each environment is characterized by specific soil properties and climatic conditions that may affect the productivity of maize (Katsenios et al., 2021). According to Feng (2024), genotype and environmental interactions play a significant role in determining maize grain yield and quality. Different genotypes respond variably to environmental factors such as drought, low soil fertility, and planting density, which can significantly influence grain yield as well as protein content and other quality traits.

The correct selection and the regional distribution of maize hybrids, together with the proper application of agrotechnical practices, are of vital importance for the yield amounts and the quality of the produce (Bahtiar et al., 2023; Shahini et al., 2023). To identify the most suitable hybrid for a given cultivation area, newly developed maize hybrids must be studied under different environmental and cultivation conditions. Such analysis enables the farmer to select the appropriate hybrid based on their yield potential under the specific soil and climatic conditions (Ion et al., 2013; Feng et al., 2022; Ocwa et al., 2023; Șimon et al., 2023b; Liu et al., 2024). For this reason, the continuous introduction and evaluation of new maize hybrids that are most suitable and efficient for the separate microregions of Bulgaria is necessary (Georgieva et al., 2023; Dimitrov, 2024; Nankova et al., 2025). Therefore, the objective of the present study was to determine the grain yield and its components, as well as certain qualitative characteristics, of five maize hybrids cultivated in North-Eastern Bulgaria.

## MATERIAL AND METHODS

### Field experiment

The field trials took place in a selected area of Targovishte (North-Eastern Bulgaria) during the period 2021-2023 with five maize hybrids: P 9241 (FAO 370), P 9610 (FAO 375), DKC 4670 (FAO 380), ES METHOD (FAO 380), and KNEJA-435 (FAO 400). The randomized complete block design was used with four replications and a plot size of 25 m². Wheat was used as a predecessor. The experiment was performed on dark gray forest soil.

Stubble plowing was performed in August after the harvest of the preceding crop, followed by deep plowing at a depth of 28-30 cm in October. Pre-sowing cultivation with harrowing was performed twice: in March and April. Fertilization was applied in autumn before deep plowing with 8 kg $ha^{-1}$ active substance phosphorus (P) and 10 kg $ha^{-1}$ active substance potassium (K) and before sowing with 18 kg $ha^{-1}$ active substance nitrogen (N).

The sowing was performed during the second decade of April with row spacing of 70 cm and a sowing rate of 70,000 germinating seeds per hectare at a depth of 6-8 cm. For weed control, the herbicide Spectrum (1300 ml $ha^{-1}$) was applied before sowing, while Elumis (1800 ml $ha^{-1}$) was applied during maize vegetation. All technological practices recommended for maize cultivation under non-irrigated conditions were followed during the growing period.

Harvesting was done at full maturity. The grain yield was determined with a standard grain moisture value of 13%. The indices evaluated were the length of the cob (LC), number of rows per cob (NR), number of grains per row (NG), mass of the cob (CW), weight of grains per cob (WG), grain yield (GY), weight of 1000 grains (TS), test weight (TW), and crude protein (CP).

**Statistical Analysis**

The experimental data were processed using analysis of variance (ANOVA) to determine the effects of the studied factors on the investigated traits. The differences between the variants were evaluated using Duncan's multiple range test at a significance level of $P \leq 0.05$. Pearson correlation analysis with scatter plots was performed to assess the relationships between the studied traits using XLSTAT 2016.02 software (Addinsoft, 2016). The stability of the studied maize hybrids was confirmed using the deviation from regression ($S^2di$), following the method of Eberhart and Russell (1966). The calculations were performed using the online software STABILITYSOFT (Pour-Aboughadareh et al., 2019).

**Weather Conditions**

Climatic factors such as temperature, rainfall, and soil water reserves during the vegetation period strongly influence the growth, development, and productivity of maize (Węgrzyn et al., 2022; Șimon et al., 2023a; Feng, 2024; Liu et al., 2024; Özdemir and Sade, 2024). According to Basir et al. (2018), moisture stress occurring at critical growth stages (anthesis and grain filling) can lead to yield losses in maize. The most critical period for water stress in maize occurs 10-14 days before and after flowering. Grain yield can be reduced two to three times more when water deficit coincides with flowering compared to other growth stages (Grant et al., 1989; Șimon et al., 2023b).

Széles et al. (2023) reported that maize yield losses may vary from 30% to 90%, depending on the intensity and duration of drought stress. Drought occurring during the silking and grain-filling stages may cause yield reductions of approximately 50% and 21%, respectively (Liang et al., 2020).

Figure 1 presents the rainfall amounts recorded during the period from April 2021 to September 2023. The first experimental year (2021) was characterized by sufficient and evenly distributed precipitation, which fully satisfied the water requirements of the plants from emergence to ripening. The total rainfall during the vegetation period reached 428 mm, which was 84 mm higher than the multiannual average (344 mm).

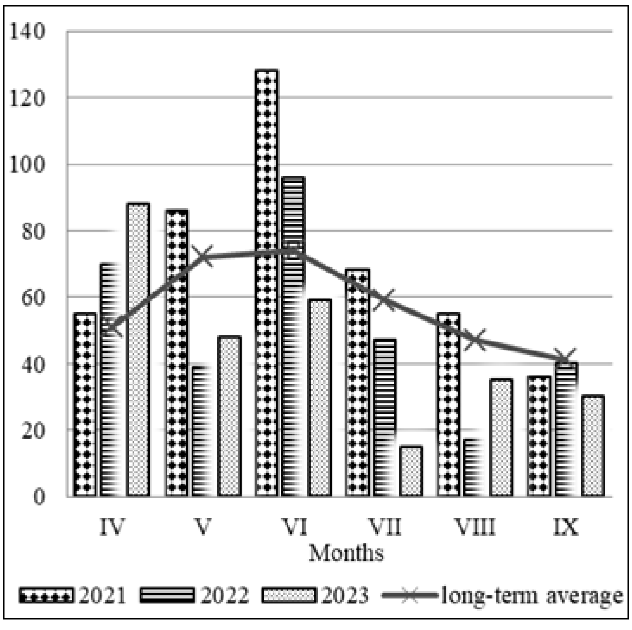


*Figure 1.* Precipitation (mm)

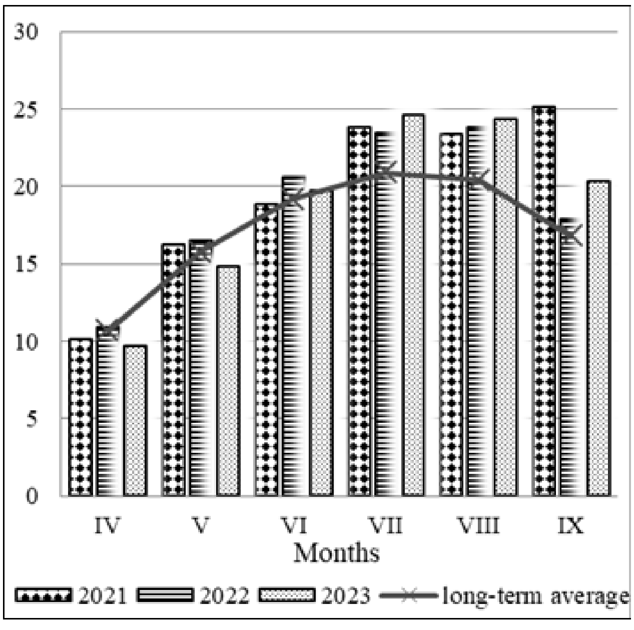


*Figure 2.* Average monthly air temperature (°C)

The lowest precipitation recorded in 2023 was 195 mm, which is approximately 149.0 mm less than the multiannual total of 344 mm. This year was marked by an irregular distribution of rainfall, insufficient to satisfy the water requirements of maize plants throughout critical stages. During the 2022 growing season, the total rainfall amounted to 309 mm, which was 35 mm below the multiannual average; however, precipitation was relatively well distributed during the vegetation period.

The average monthly temperatures during the study period (2021-2023) were close to or slightly higher than the long-term average values and did not deviate substantially from the crop requirements (Figure 2).

Out of all the studied years, 2021 provided the most advantageous conditions for the growth and development of maize hybrids due to the optimal interplay of temperature and precipitation during the critical phases of development. This was followed by 2022, while 2023 was the least favorable year because of the pronounced moisture deficit, which affected maize productivity and grain quality.

## RESULTS AND DISCUSSION

### Grain Yield

The effects of the studied factors (hybrid and year) on grain yield are presented in Table 1. Among the investigated hybrids, DKC 4670 showed the highest average grain yield for the study period, reaching 5893 kg ha$^{-1}$ and surpassing all other hybrids included in the experiment.

*Table 1*. Grain yield and related traits of the studied maize hybrids

| Variables | | Grain yield (kg ha$^{-1}$) | Cob length (cm) | Number of rows per cob | Number of grains per row | Cob weight (g) | Grain weight per cob (g) |
|---|---|---|---|---|---|---|---|
| Years (A) | 2021 | 6888 [a] | 18.8 [a] | 16.0 [a] | 34.5 [a] | 217 [a] | 159 [a] |
| | 2022 | 5852 [b] | 17.6 [b] | 15.2 [b] | 32.2 [b] | 196 [b] | 137 [b] |
| | 2023 | 5371 [c] | 16.0 [c] | 14.4 [c] | 28.2 [c] | 180 [c] | 122 [c] |
| Hybrid (B) | P 9241 | 5990 | 17.7 | 14.3 | 32.7 | 185 | 138 |
| | P 9610 | 6187 | 18.1 | 15.1 | 31.0 | 211 | 145 |
| | DKC 4670 | 6641 | 18.9 | 17.1 | 35.5 | 232 | 163 |
| | ES METHOD | 5774 | 17.0 | 15.9 | 28.2 | 196 | 128 |
| | KNEJA-435 | 5593 | 15.7 | 13.5 | 32.3 | 165 | 122 |
| 2021 | P 9241 | 7050 [b] | 18.8 [c] | 14.6 [c] | 37.0 [b] | 197 [d] | 155 [c] |
| | P 9610 | 6880 [c] | 19.4 [b] | 16.4 [b] | 34.0 [d] | 233 [b] | 164 [b] |
| | DKC 4670 | 7390 [a] | 20.5 [a] | 18.0 [a] | 39.0 [a] | 263 [a] | 196 [a] |
| | ES METHOD | 6740 [d] | 18.4 [c] | 16.8 [b] | 31.0 [e] | 205 [c] | 144 [d] |
| | KNEJA-435 | 6380 [e] | 17.1 [d] | 14.0 [d] | 36.0 [c] | 186 [e] | 136 [e] |
| 2022 | P 9241 | 5710 [c] | 17.9 [ab] | 14.3 [d] | 32.5 [c] | 184 [d] | 134 [c] |
| | P 9610 | 6060 [b] | 18.1 [a] | 15.1 [c] | 31.0 [d] | 208 [b] | 141 [b] |
| | DKC 4670 | 6640 [a] | 18.6 [a] | 17.1 [a] | 35.5 [a] | 229 [a] | 160 [a] |
| | ES METHOD | 5470 [d] | 17.3 [b] | 15.9 [b] | 28.5 [e] | 196 [c] | 127 [d] |
| | KNEJA-435 | 5380 [e] | 16.1 [c] | 13.5 [e] | 33.5 [b] | 165 [e] | 121 [e] |
| 2023 | P 9241 | 5210 [c] | 16.5 [b] | 14.0 [c] | 28.7 [b] | 173 [d] | 124 [c] |
| | P 9610 | 5621 [b] | 16.8 [b] | 13.8 [c] | 28.0 [c] | 192 [b] | 129 [b] |
| | DKC 4670 | 5893 [a] | 17.5 [a] | 16.2 [a] | 32.0 [a] | 205 [a] | 133 [a] |
| | ES METHOD | 5112 [d] | 15.2 [c] | 15.0 [b] | 25.0 [d] | 186 [c] | 114 [d] |
| | KNEJA-435 | 5018 [e] | 14.0 [d] | 13.0 [a] | 27.5 [c] | 143 [e] | 110 [e] |
| Anova | A | ** | ** | * | * | * | * |
| | B | ** | * | * | * | * | * |
| | A × B | * | ns | * | ns | * | * |

*¹Means within columns followed by different lowercase letters are significantly different at P ≤ 0.05 according to the LSD test. *F-test significant at P ≤ 0.05; **F-test significant at P ≤ 0.01; ns - non-significant.*

Grain yield varied considerably depending on the year of cultivation, which confirms the strong influence of climatic conditions on maize productivity (Mandić et al., 2011; Ngoune Tandzi and Mutengwa, 2019; Epule et al., 2022). The main reason for the lower grain yield in 2023 was the uneven distribution of rainfall, especially the lack of rain during the stages of inflorescence formation and flowering. The differences compared with the first and the second experimental years were statistically significant. Significant differences were also observed among the studied hybrids. The lowest average grain yield was recorded for hybrid KNEJA-435 (5018 kg ha$^{-1}$). During the second experimental year, grain yield varied from 5380 to 6640 kg ha$^{-1}$. In contrast, in 2021 the more favorable climatic conditions led to higher values of this trait, with grain yield reaching up to 7390 kg ha$^{-1}$.

Statistical processing of the data showed that the differences between all studied hybrids were significant. Zhou et al. (2016) reported considerable variation in maize grain yield due to differences in weather conditions. According to Peng et al. (2021), water availability is a key factor for maize productivity, and water scarcity has become a critical problem that must be overcome to increase grain yield. During the study period (2021-2023), hybrid DKC 4670 showed the highest grain yield and significantly surpassed the hybrids KNEJA-435, ES METHOD, P 9241, and P 9610 by 17.4%, 15.2%, 13.1%, and 4.8%, respectively.

The analysis of variance showed a strong and statistically significant impact of both studied factors (hybrid and year), reflecting the influence of specific climatic conditions. An interaction between hybrid and year was also observed, indicating that the performance of the maize hybrids varied depending on the environmental conditions during the studied years.

**Cob Length**

Cob length is one of the important yield components contributing to grain yield in maize (Cheema et al., 2010; Marchenko, 2019). The obtained results indicated that this trait was significantly affected by the studied hybrids as well as by the climatic conditions during the experimental years. In the first experimental year (2021), cob length varied from 17.1 cm in hybrid KNEJA-435 to 20.5 cm in hybrid DKC 4670. In 2022, the values of this indicator were on average 6.8% lower, ranging from 16.1 to 18.6 cm. In 2023, cob length varied from 14.0 to 17.5 cm, which was 17.5% and 10.0% lower compared with 2021 and 2022, respectively. On average for the study period, hybrid DKC 4670 realized a cob length of 18.9 cm and surpassed the other studied hybrids.

The analysis of variance (ANOVA) confirmed that both factors (hybrid and year) had a statistically significant effect on cob length, while their interaction showed no significant influence on this trait.

**Number of Rows per Cob**

The number of rows per cob is a genetically determined characteristic (Genov and Genova, 2005; Valkova, 2007). The recorded values ranged from 14.0 to 18.0 in 2021, from 13.5 to 17.1 in 2022, and from 13.0 to 16.2 in 2023.

These results indicate that this characteristic was less affected by the climatic conditions during the study years compared with cob length. The highest number of rows per cob was observed in hybrid DKC 4670, while the lowest values were recorded in hybrid KNEJA-435 as well as across the individual years and on average for the entire experimental period. With an average value of 17.1 rows per cob, hybrid DKC 4670 differed significantly from the other hybrids included in the study.

The analysis of variance confirmed that the factors hybrid and year had a statistically significant effect on the number of rows per cob. In addition, the interaction between hybrid and year also showed a statistically significant influence on this trait.

**Number of Grains per Row**

Grain yield in maize is closely related to the number of grains per row, as more grains per row generally leads to higher grain yield (Ali et al., 2020). Differences in climatic conditions during the experimental years were one of the reasons for the formation of different values of the indicator. During 2021, which was characterized by favorable conditions for plant growth and development, the highest values of the number of grains per row were reported. The values ranged from 31.0 in the hybrid ES METHOD to 39.0 in the hybrid DKC 4670. In 2023, the values of this indicator were significantly lower (on average by 25.5%) and varied from 25.0 to 32.0 grains per row, while in 2022 they ranged from 28.5 to 35.5.

The analysis of variance about the effect of the factors (hybrid and year), as well as their interaction, on the indicator "number of grains per row" shows a statistically significant effect of the studied factors and an insignificant effect of their interaction.

**Cob Weight**

The results for cob weight followed a similar trend to the previously discussed yield components. The lowest values of this trait were recorded in 2023, when climatic conditions were less favorable for the growth and development of maize compared with 2021 and 2022. The studied hybrids differed significantly in the cob weight. Out of all investigated hybrids, the lowest average cob weight during the three-year period was established in hybrid KNEJA-435 (165 g). This hybrid showed lower values compared with hybrids P 9241, ES METHOD, and P 9610 by 12.1%, 18.8%, and 27.9%, respectively. The hybrid DKC 4670 had the heaviest cob, which weighed 232 g.

The analysis of variance (ANOVA) revealed a strong and statistically proven effect of both factors - hybrid (B) and year (A) - reflecting the influence of specific climatic conditions on cob weight. A significant interaction between the hybrid and the year was also observed.

**Grain Weight per Cob**

An important yield component in maize is grain weight per cob, which has a direct influence on grain yield (Ali et al., 2020; Devasree et al., 2020). The values of this trait are influenced by several factors, including cultivation technology, weather conditions, and the genetic characteristics of the hybrid (Rizzo et al., 2022; Akhtar et al., 2023; Gao et al., 2023; Paliwal and Smith, 2024).

Differences in climatic conditions during the experimental years were one of the main reasons for the variation in grain weight per cob. The highest values were recorded in the first experimental year due to the favorable weather conditions. With a value of 136 g, hybrid DKC 4670 distinguished itself significantly from the other hybrids. During the second experimental year, grain weight per cob varied from 121 g in hybrid KNEJA-435 to 160 g in hybrid DKC 4670, with statistically significant differences among the hybrids. In line with the observations for grain yield, the lowest values of grain weight per cob were reported in the third year, when climatic conditions were less favorable for maize growth and development. On average for the study period, grain weight per cob ranged from 122 g in hybrid KNEJA-435 to 163 g in hybrid DKC 4670.

The analysis of variance (ANOVA) indicated a substantial impact of both studied factors (hybrid and year) on grain weight per cob. Their interaction also showed a significant influence on this trait.

**1000-Grain Weight**

The effect of the studied factors (hybrid and year) on the qualitative traits is presented in Table 2. The 1000-grain weight is an important yield component directly contributing to the final grain yield of maize (Tahir et al., 2008). This trait is influenced by environmental conditions, cultivation technology, and the genetic characteristics of the hybrids (Georgieva et al., 2023).

The highest 1000-grain weight was recorded in the first experimental year due to the favorable weather conditions. Hybrid P 9610 showed significantly higher values, reaching 370 g, while the lowest values were observed in hybrid KNEJA-435 (290 g). The differences among the hybrids were statistically significant. In the 2022 growing season, the 1000-grain weight ranged from 275 to 350 g, which was approximately 5.5% lower than the values noted in 2021. The lowest values of this trait were observed in the third experimental year, varying from 230 to 288 g. On average for the study period (2021–2023), the highest 1000-grain weight (328.7 g) was recorded in hybrid DKC 4670, which differed significantly from the other studied hybrids. The lowest value (265 g) was observed in hybrid KNEJA-435.

The analysis of variance (ANOVA) about the effect of the factors Hybrid and Year, as well as their interaction, on the 1000-grain weight shows a significant influence of the factors on the changes of indices and a statistically significant effect of the interaction between them.

*Table 2*. Grain quality traits of the studied maize hybrids[1]

| Variable | | 1000-grain weight (g) | Test weight (kg hL⁻¹) | Crude protein (%) |
|---|---|---|---|---|
| Years (A) | 2021 | 333.8 [a] | 74.1 [a] | 9.1 [c] |
| | 2022 | 314.6 [b] | 68.0 [b] | 9.9 [b] |
| | 2023 | 268.8 [c] | 64.0 [c] | 11.0 [a] |
| Hybrid (B) | P 9241 | 309.7 | 70.2 | 10.0 |
| | P 9610 | 342.0 | 72.3 | 9.8 |
| | DKC 4670 | 328.7 | 68.6 | 9.2 |
| | ES METHOD | 283.3 | 67.0 | 9.7 |
| | KNEJA-435 | 265.0 | 65.5 | 11.3 |
| 2021 | P 9241 | 340 [c] | 75.6 [b] | 9.10 [b] |
| | P 9610 | 370 [a] | 77.5 [a] | 8.90 [b] |
| | DKC 4670 | 358 [b] | 74.1 [c] | 8.31 [c] |
| | ES METHOD | 311 [d] | 72.2 [d] | 8.50 [c] |
| | KNEJA-435 | 290 [e] | 71.3 [e] | 10.6 [a] |
| 2022 | P 9241 | 322 [c] | 69.2 [b] | 10.2 [b] |
| | P 9610 | 350 [a] | 71.1 [a] | 9.81 [b] |
| | DKC 4670 | 340 [b] | 68.0 [c] | 9.10 [c] |
| | ES METHOD | 286 [d] | 67.2 [d] | 9.50 [c] |
| | KNEJA-435 | 275 [e] | 64.4 [e] | 11.1 [a] |
| 2023 | P 9241 | 267 [c] | 65.9 [b] | 10.8 [b] |
| | P 9610 | 306 [a] | 68.2 [a] | 10.6 [b] |
| | DKC 4670 | 288 [b] | 63.8 [c] | 10.2 [c] |
| | ES METHOD | 253 [d] | 61.5 [d] | 11.0 [b] |
| | KNEJA-435 | 230 [e] | 60.7 [e] | 12.2 [a] |
| Anova | A | * | * | ** |
| | B | * | * | * |
| | A × B | ns | * | ns |

*[1]Means within columns followed by different lowercase letters are significantly different at $P \leq 0.05$ according to the LSD test. *F-test significant at $P \leq 0.05$; **F-test significant at $P \leq 0.01$; ns - non-significant.*

**Test Weight**

Test weight is influenced by both the genetic characteristics of the hybrids and the climatic conditions during the growing season. In the third experimental year (2023), the limited rainfall during the grain-filling and maturity stages had a negative effect on this trait compared with the conditions observed in 2021 and 2022.

The lowest test weight values were recorded in hybrids KNEJA-435 and ES METHOD, reaching 60.7 kg hL$^{-1}$ and 61.5 kg hL$^{-1}$, respectively. Hybrid P 9610 differed significantly from the other hybrids by showing the highest value (68.2 kg hL$^{-1}$). The highest test weight values were established in the first experimental year (2021), ranging from 71.3 to 77.5 kg hL$^{-1}$. During the three-year study period, values above 72.3 kg hL$^{-1}$ were documented for hybrid P 9610.

The analysis of variance (ANOVA) showed that both factors (hybrid and year) had a statistically significant effect on test weight, while their interaction did not show a significant influence on this trait.

**Crude Protein Content**

The crude protein content of maize depends on various factors, including the hybrid, environmental conditions, and the interaction between them (Abakemal et al., 2016; Katsenios et al., 2021). In addition to genetic factors, the variability of protein content in maize is strongly influenced by environmental conditions such as location, precipitation during the growing season, and nutrient supply (Gyuricza et al., 2012; Széles et al., 2018; An and Kong, 2022; Vasilev, 2022; Datsko et al., 2024).

Gyuricza et al. (2012) stated that lower crude protein values and higher grain yields are often observed during years with higher precipitation, while Széles et al. (2018) found that protein content may decrease by approximately 11.7% in dry and warm years compared with wetter years.

In contrast to the previously discussed quantitative and qualitative traits, the crude protein content in the present study was higher during years with reduced precipitation. In the third experimental year, total precipitation measured 195 mm, which was 233 mm and 114 mm less than in the first and second experimental years, respectively.

In 2023, the five studied hybrids exhibited the greatest crude protein values, ranging from 10.2% in hybrid DKC 4670 to 12.2% in hybrid KNEJA-435. In comparison, during 2021 and 2022 the crude protein values were approximately 15-22% and 10-12% lower, respectively. The obtained differences were statistically significant. On average for the study period (2021-2023), hybrid KNEJA-435 showed the highest crude protein content (11.3%) and surpassed hybrids P 9241, P 9610, ES METHOD, and DKC 4670 by 13.0%, 15.3%, 16.5%, and 22.8%, respectively (Table 2). The obtained results also indicate that the hybrid with the highest crude protein content showed the lowest grain productivity, confirming the commonly observed inverse relationship between grain yield and protein content (Georgieva et al., 2023; Delibaltova, 2025).

The analysis of variance (ANOVA) revealed a statistically significant influence of the factors hybrid and year on crude protein content, while their interaction showed an insignificant effect.

**Correlation Analysis**

To determine the relationships between the studied variables (quantitative and qualitative traits) in the investigated maize hybrids, a correlation analysis was performed. The correlation coefficients (r) between the variables were calculated and presented both numerically and graphically through scatter plots illustrating the relationship between the main trait, grain yield, and the remaining indicators (Figure 3).

Grain yield is directly related to all other quantitative indicators, with the values of the correlation coefficients varying widely, but always remaining positive.

All structural elements of yield have a direct impact on grain yield in the studied maize hybrids. The strongest influence on grain yield ($r > 0.900$) was exerted by the traits grain mass per cob ($r = 0.930$) and cob length ($r = 0.905$). These two traits have highly concentrated ellipses in the correlation scatter, which indicates a strong correlation. The structural elements of grain yield - number of grains per row and cob mass - also show a high positive correlation ($r > 0.800$). Although positive and high, the influence of the trait, number of rows per cob, is the weakest compared with the others ($r = 0.700$). For this trait, the correlation dispersion is also the highest.

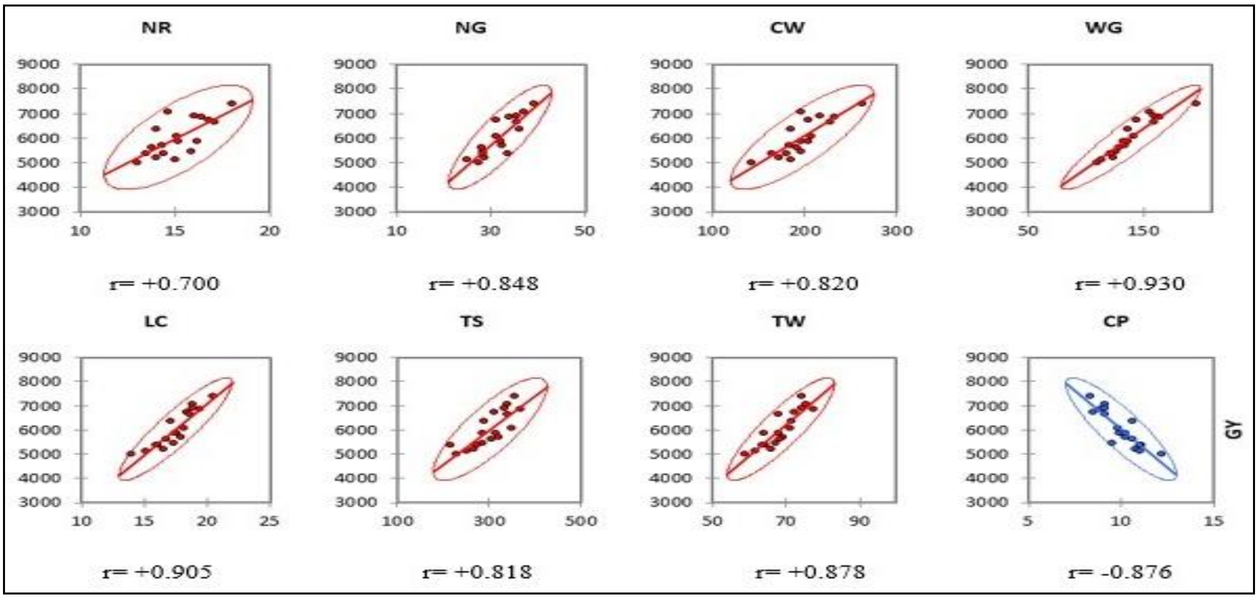


*Figure 3.* Pearson correlation coefficients (r) and scatter plots between grain yield (GY) and the main indices

The relationship between grain yield and quality indicators is ambiguous. The two indicators determining the physical qualities of grain (1000-grain weight and the test weight) are positively related to yield, with high correlation coefficients of r = 0.818 and r = 0.878, respectively. A strong negative correlation was reported between grain yield and crude protein content (r = -0.876). The strongly clustered ellipse of the correlation scatter indicates that this negative correlation is highly significant.

There are many models for determining yield stability in agricultural crops. In the online program STABILITYSOFT, used for calculating stability, there is an opportunity to make a relationship between yield (Y) and all 16 provided models through correlation analysis between yield (Y) and the obtained coefficients. In the present study, deviation from regression ($S^2di$) was used to determine and rank the stability of the studied maize hybrids due to its strongest positive correlation with yield (r = 0.730) (Figure 4).

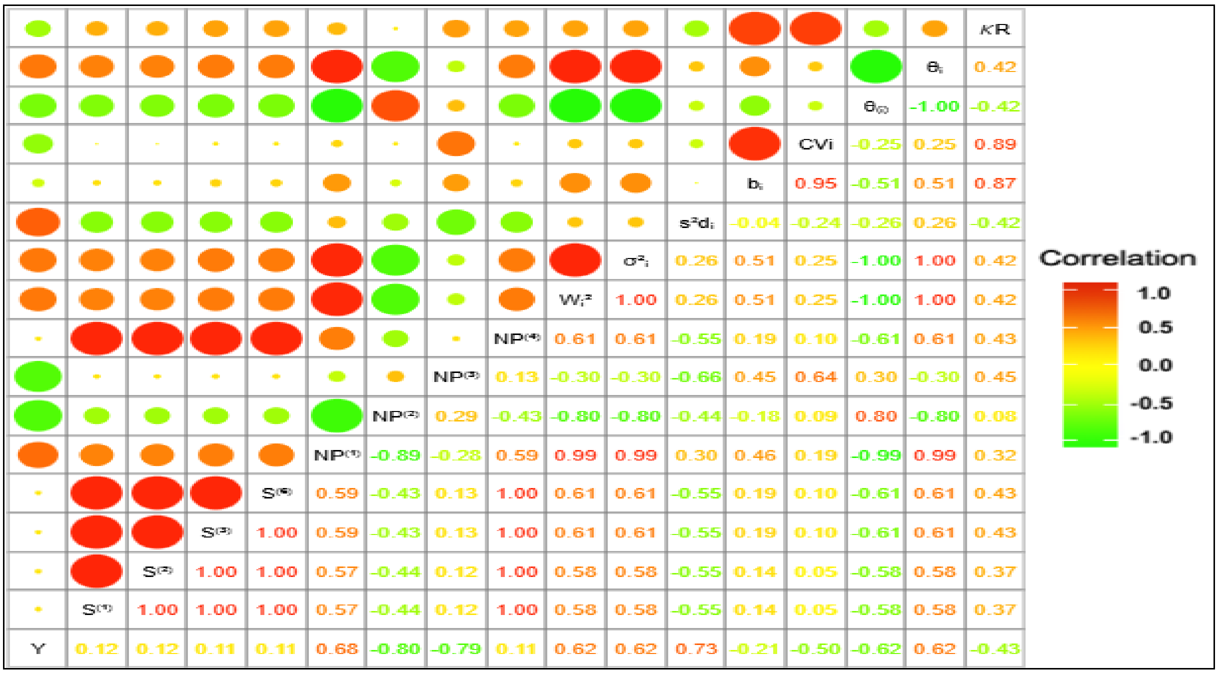


*Figure 4.* Correlation analysis between grain yield (Y) and stability coefficients

In addition to the regression slope, the variance of deviations from regression ($S^2di$) has been suggested as one of the most commonly used parameters for the selection of stable genotypes. Genotypes with $S^2di = 0$ are considered the most stable, while $S^2di > 0$ indicates lower stability across environments. Therefore, genotypes with lower values are the most desirable.

The obtained results show that the most stable hybrid under different environmental conditions was P 9610, followed by hybrids KNEJA-435, P 9241, and ES METHOD. The least stable hybrid was DKC 4670, which showed the highest average grain yield (Table 3). This indicates that high productivity is not always associated with stability under varying environmental conditions.

*Table 3.* Deviation from regression ($S^2di$) in the studied maize hybrids

| Hybrids | Deviation from regression $S^2di$ | Rank |
|---|---|---|
| P 9241 | 636.913 | 3 |
| P 9610 | 143.638 | 1 |
| DKC 4670 | 6755.691 | 5 |
| ES METHOD | 2285.929 | 4 |
| KNEJA-435 | 446.451 | 2 |

## CONCLUSIONS

The productivity of the tested hybrids was determined by both their genetic background and the weather conditions during the experimental years. In contrast to grain yield and the other qualitative and quantitative traits, crude protein content was higher in years characterized by lower precipitation. Hybrid KNEJA-435 was distinguished by the highest crude protein content (11.3%).

The highest grain yield observed in hybrid DKC 4670 was mainly associated with its superior cob weight and grain mass per cob. Grain yield and crude protein content were negatively correlated. The highest values of the indicators 1000-grain weight and test weight were recorded in hybrid P 9610.

Among the evaluated maize hybrids for the Targovishte region, hybrid DKC 4670 is recommended for cultivation due to its relatively high productivity and acceptable grain quality under contrasting climatic conditions, although it exhibited lower stability in terms of genotype × environment interaction. In contrast, P 9610 showed the highest yield stability across environments. The strongest positive effects on grain yield were recorded for grain mass per cob and cob length, while a negative relationship was observed between grain yield and crude protein content.

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