The Anthesis–Silking Interval and its Relation to Certain Yield Components in Maize Hybrids from the Mid-Early FAO Group

Interval između metličanja i svilanja te njegova povezanost s određenim komponentama prinosa kod hibrida kukuruza iz srednje rane FAO grupe

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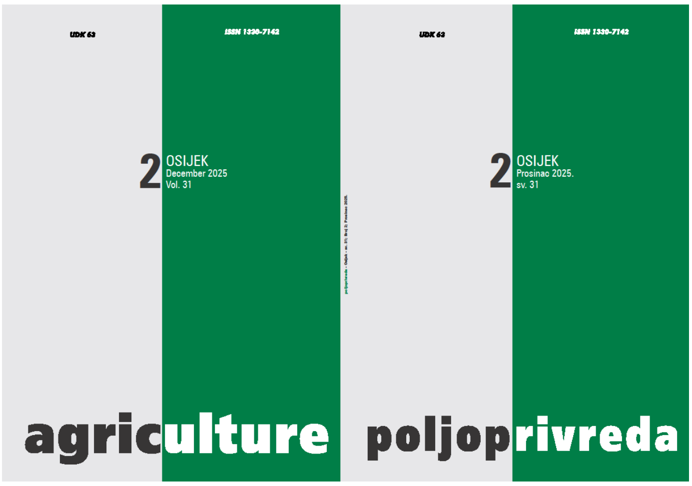

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THE ANTHESIS–SILKING INTERVAL AND ITS RELATION TO CERTAIN YIELD COMPONENTS IN MAIZE HYBRIDS FROM THE MID-EARLY FAO GROUP

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SUMMARY

In the present study, variation, correlation relationships, and grouping among four agronomically important traits in maize were examined: the anthesis-silking interval (ASI), grain yield (GY), ear length (EL), and the number of rows per ear (RN). A total of 75 maize hybrids from the mid-early maturity group (FAO 400–500), tested in competitive variety trials over a three-year period (2022–24), were evaluated. The aim of the study was to assess the importance of the anthesis-silking interval and its effect on the grain yield. The results demonstrate a strongly negative impact of increased ASI (up to 5 days) on grain yield in 2024, as confirmed by both simple and multiple correlation analyses. The cluster analysis, conducted using Ward's method and presented as a dendrogram, grouped the hybrids and provided a useful tool for evaluating the optimal combination of the studied traits within a single genotype. The selection of hybrids with a short or even negative anthesis-silking interval can be employed as an indirect method for drought tolerance selection, also known as a tandem selection.

Keywords: maize hybrids, ASI, grain yield, simple and multiple correlation, cluster analysis

INTRODUCTION

According to numerous Food and Agriculture Organization (FAO) of the United Nations reports, abiotic stress factors resulting from anthropogenic activity are expected to become increasingly frequent and acute, adversely affecting and reducing the yields of the world's major cereal crops in the future (Bruinsma, 2017). Within the context of global climatic changes, maize (*Zea mays* L.) cannot remain unaffected by such developments (Santos et al., 2020). Ensuring stable and predictable yields moving forward necessitates a shift in agronomic practices and a reorientation of breeding objectives for major agricultural crops - both across Europe (Parent et al., 2018) and in Bulgaria (Georgieva et al., 2022).

The period required for silk growth and emergence is of critical importance for grain yield formation in maize hybrids under drought conditions. When water scarcity occurs prior to the onset of flowering (Tsimba et al., 2013; Ao et al., 2020), silk development and emergence are delayed, while tassel emergence remains relatively unaffected. As a result, the interval between the emergence of the plant's reproductive organs is extended (Bassetti & Westgate, 1993a; Fuad-Hassan et al, 2008; Santos et al., 2020). This critical phase of plant development is referred to as the "anthesis–silking interval," or ASI, and is measured in days.

The interval serves as a highly reliable indicator of the overall stress tolerance of maize plants under various adverse abiotic conditions, such as: soil water deficit (Bassetti & Westgate, 1993b; Fuad-Hassan et al., 2008); nutrient deficiency—particularly in limited nitrogen availability cases (Lima et al., 2023); challenges associated with the introduction of exotic germplasm, including long photoperiods, high elevation, and lack of thermal adaptation (Tsimba et al., 2013); and excessive plant density beyond recommended sowing rates (Tokatlidis & Koutroubas, 2004), among others.

Under optimal growing conditions, characterized by a high agronomic background and the absence of stress factors, flowering of the reproductive organs occurs in

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perfect synchrony, i.e., ASI = 0. In some cases, the interval may even take on negative values (ASI = –1 or –2) when silks emerge prior to the tassel (Lima et al, 2023), which is a desired manifestation of this trait. Studies conducted by Abera et al., (2021) under the conditions of Eastern Africa (Uganda) report mean ASI values of 1.0–1.5 days in open-pollinated varieties (OPVs) and synthetic populations. In Kenya, Kahiu et al., (2013) compared early-maturing local populations (which exhibited longer ASI durations) with CIMMYT-provided lines that had longer vegetative periods but significantly shorter ASI values. The ASI range in local populations was 7 to 10 days, whereas the CIMMYT lines showed intervals of 2 to 4 days. The combination of these traits in hybrid progenies creates favorable conditions for selecting earlier forms with a shorter reproductive flowering period. In F_2 generations of topcrosses, the highest frequency was observed among those with ASI values of 1–2 days. In drought-tolerance selection trials involving six tropical maize populations introduced to the highland regions of Morelos state (Central Mexico), Bolaños & Edmeades (1996) reported that, under drought conditions and ASI values exceeding 5 days, grain yield decreased by up to 20%. When the interval extended beyond 10–12 days, a total crop failure was observed.

In addition to the abiotic factors, agronomic practices also influence the anthesis-silking interval (ASI). According to studies by Elmore (2012), Tsimba et al., (2013), Santos et al., (2020), and others, the model of "earlier sowing - higher yield" in maize does not always guarantee superior outcomes.

During peak silking, water consumption per plant can reach up to 10 l/m^2 per day (Vulchinkov & Vulchinkov, 2023), meaning that the specific conditions of the year directly affect the flowering period, thereby serving as an indicator of stress tolerance.

Tokatlidis & Koutroubas (2004) report that higher planting densities lead to an increase in the number of barren plants, particularly affecting the older maize hybrid generations with a spreading leaf architecture that are intolerant to crowding. Such hybrids, when grown at standard densities, typically exhibit ASI values of 2–3 days in favorable conditions. Under drought stress, this interval may extend to up to a week, resulting in a sharp decline in yield. In contrast, modern hybrid generations display a minimal (often nearly zero) ASI, indicating complete synchronization in the flowering of reproductive organs (Valkova, 2012; Vulchinkov & Vulchinkov, 2023).

Edmeades et al., (2000) developed a mathematical model in which grain yield (a) and the number of ears per plant (b) are in exponential dependence on the flowering interval of the reproductive organs, expressed as $GY = exp^{a+b*ASI}$. The correlation between grain yield and ASI is negative and nonlinear – an observation that has been investigated and confirmed under both stress and non-stress growing conditions (Kim et al., 2017; Lima et al., 2023). Bolanos & Edmeades (1996) reported that under stress conditions, the heritability of ASI increases, while grain yield decreases. Lima et al., (2023) confirmed this pattern but also emphasized that ASI cannot be used as a definitive predictor of yield outcomes. Further research in this direction would contribute to greater clarity in resolving this question.

The objective of the present study is to investigate the variation and correlation relationships between the anthesis–silking interval (ASI) and some yield components in 75 experimental maize hybrids from the mid-early maturity group (FAO 400–500) over a three-year period (2022–24).

MATERIAL AND METHODS

The study was conducted at the experimental field of the Maize Research Institute – Knezha (5835, Knezha, Pleven, Bulgaria) and involved a competitive varietal trial (KSO) comprising 25 crosses from the mid-early maturity group according to the FAO classification (400–500) over a three-year period (2022, 2023, and 2024), resulting in a total of 75 experimental hybrids. The official standards, in accordance with the state variety testing agency, included in the trial were as follows:

1) 2022 – P0217 (G1); Konfites (G10); Kneja 435 (G20).
2) 2023 – P9903 (G1); Kneja 435 (G10); P0937 (G17).
3) 2024 – Kneja 435(G1); P0023 (G10); P8904 (G20).

The trials were laid out in a randomized complete block design (RCBD) with two replications, on 10 m^2 harvested plots, under non-irrigation conditions, following the cultivation technology established at the Maize Research Institute—Knezha. The recorded traits are as follows: Anthesis–silking interval, (ASI, days); grain yield (GY, t/ha) at standard moisture of 14%; ear length (EL, cm) and number of rows per ear (RN). The studied traits were subjected to one-way analysis of variance (ANOVA) according to Genchev et al., (1975); simple (Pearson) and multiple correlation analysis (Genchev et al., 1975); and hierarchical cluster analysis following the method of Ward (1963). Data processing and statistical analysis were performed using Microsoft Excel and SPSS-25 software.

RESULTS AND DISCUSSION

The meteorological conditions for the trial period are presented in Table 1. The analysis of average monthly temperatures over the three-year period reveals a pronounced contrast between the 2024 growing season and the previous two years, particularly during the summer months of June, July, and August, which are critical for crop development and grain yield formation. The temperature ranges for these three months in 2022 and 2023 varied between 20.4°C (June 2023) and 24.7°C (July 2022). In comparison, for the same period in 2024, the temperatures ranged from 24.9°C (June) to 26.1°C (July), clearly identifying 2024 as a much hotter year relative to the others. Total precipitation during the growing season across the trial years was markedly variable: 291.1 l/m^2 in 2022; 327.4 l/m^2 in 2023; and only 214.9 l/m^2 in 2024.

Table 1. Meteorological report on 2022-24 growing seasons at the experimental field of Maize Research Institute—Knezha

Tablica 1. Meteorološko izvješće o vegetacijskim sezonama 2022. – 2024. na pokusnome polju Instituta za istraživanje kukuruza — Knezha

Average Month Temperatures (°C) / *Prosječne mjesečne temperature zraka (°C)*	2022	2023	2024	**Average Month Precipitations (l/m^2)** / *Prosječne mjesečne količine oborina (l/m^2)*	2022	2023	2024
April / Travanj	11.0	11.1	14.3	April / Travanj	67.3	45.6	35.0
May / Svibanj	17.4	16.1	16.3	May / Svibanj	35.1	71.5	82.7
June / Lipanj	21.8	20.4	24.9	June / Lipanj	75.1	94.1	25.6
July / Srpanj	24.7	24.6	26.1	July / Srpanj	12.6	71.3	42.3
August / Kolovoz	24.2	22.4	26.0	August / Kolovoz	74.8	23.8	2.1
September / Rujan	17.8	20.5	19.0	September / Rujan	27.2	21.1	27.2
				Sum (Σ)	292.1	327.4	214.9

According to meteorological data, the 2022 season may be considered favorable for maize production and 2023 as a close to optimal for the crop, thus making it a relatively highly favorable year. In contrast, the 2024 growing season was marked by extremely unfavorable conditions—a very high average monthly temperatures and a pronounced precipitation deficit during the crop's critical developmental phases. Additionally, the occurrence of "tropical nights"—a phenomenon atypical for this geographic region, characterized by the absence of diurnal temperature variation and lack of nighttime cooling was observed (Vulchinkov & Hristova-Cherbazhi, 2025).

The results of the combined one-way analysis of variance for the traits ASI, GY, EL, and RN of 25 hybrids tested in competitive varietal trials (KSO) for the years 2022, 2023, and 2024 are presented in Tables 2, 3, and 4, respectively.

Table 2. Joint analysis of variance for the evaluated characteristics in KSO-2022

Tablica 2. Zajednička analiza varijance za analizirana svojstva u KSO-2022

Source of Variation / *Izvori varijacije*	df	***Mean Squares*** / *Srednji kvadrati* ***(MS)***			
		ASI	GY	EL	RN
Replications */Repeticije*	1	3.00^{ns}	3.4800^{**}	7.20^{*}	1.20^{ns}
Genotypes */Genotipovi*	24	4.50^{**}	1.1042^{**}	2.58^{*}	3.50^{**}
Residual *Error / Rezidualna pogreška*	24	1.10	0.3875	0.70	0.78
Corrected *Total / Korigirani total*	49				

*****- significant at*** / *značajno na razini pouzdanosti* $P < 0.01$; * ***- significant at*** / *značajno na razini pouzdanosti* $P < 0.05$; ^{ns} ***– not significant*** / *nije značajno*

The results for the 2022 trial indicate statistically significant differences among genotypes for all traits at probability levels of $P < 0.01$ and $P < 0.05$. No significant differences were observed between replications for the ASI period and the number of rows per ear. However, significant differences were detected for ear length and grain yield, with the latter showing a high level of significance at $P < 0.01$.

Table 3 presents the results of the analysis of variance for the 2023 trial. A similar trend to the previous year was observed regarding the genotype effect, with all four evaluated traits showing statistically significant differences at the $P < 0.01$ level. As in 2022, no significant differences were found between replications for the anthesis–silking interval and the number of rows per ear. However, both grain yield and ear length exhibited highly significant differences, also at the $P < 0.01$ level.

Table 3. Joint analysis of variance for the evaluated characteristics in KSO-2023

Tablica 3. Zajednička analiza varijance za analizirana svojstva u KSO-2023

Source of Variation / *Izvori varijacije*	df	***Mean Squares*** / *Srednji kvadrati* ***(MS)***			
		ASI	GY	EL	RN
Replications */Repeticije*	1	1.20^{ns}	3.3784^{*}	8.50^{**}	0.01^{ns}
Genotypes */Genotipovi*	24	2.52^{**}	1.8952^{**}	2.04^{**}	3.79^{**}
Residual *Error / Rezidualna pogreška*	24	0.32	0.4366	0.28	0.53
Corrected *Total / Korigirani total*	49				

*****- significant at*** / *značajno na razini pouzdanosti* $P < 0.01$; ^{ns} ***– not significant*** / *nije značajno*

The variation analysis for the final year of the study (2024) is presented in Table 4. In contrast to the previous two years, which were relatively similar in terms of their outcomes, certain differences were observed. Specifically, there was no statistically significant variation in the number of rows per ear between replications, nor in ear length among genotypes.

Table 4. Joint analysis of variance for the evaluated characteristics in KSO-2024

Tablica 4. Zajednička analiza varijance za analizirana svojstva u KSO-2024

Source of Variation / *Izvori varijacije*	df	***Mean Squares*** / *Srednji kvadrati* ***(MS)***			
		ASI	GY	EL	RN
Replications */Repeticije*	1	4.50^{ns}	3.5240^{**}	9.50^{*}	1.00^{ns}
Genotypes */Genotipovi*	24	4.79^{*}	1.1667^{*}	3.00^{ns}	2.17^{*}
Residual *Error / Rezidualna pogreška*	24	1.50	0.4375	2.00	0.81
Corrected *Total / Korigirani total*	49				

*****- significant at*** / *značajno na razini pouzdanosti P < 0.01;* ^{ns} ***– not significant*** / *nije značajno*

Summarizing the ANOVA results across the entire three-year study period, the ASI did not exhibit statistically significant differences attributable to environmental conditions (replications). However, statistically significant differences were observed among genotypes, albeit at varying levels of significance (P < 0.01 and/or P < 0.05).

Table 5 presents the average data for the studied traits, along with the calculated least significant differences (LSDs) for the entire study period. Regarding the ASI interval, the range of values in 2022 was from –0.5 to +2.0 days, with an LSD of 2.17, indicating that no statistically significant differences were observed among the hybrids. This suggests that the genotypes responded similarly to the environmental conditions during that year.

Table 5. Mean values of anthesis-silking period, grain yield, ear length and ear rows number for three years 'period (2022-24)

Tablica 5. Srednje vrijednosti razdoblja metličanja – svilanja, prinosa zrna, duljine klipa i broja redova zrna za trogodišnje razdoblje (2022. – 2024.)

Hybrid / *Hibrid*	**ASI** / *razdoblje metličanja–svilanja*			**GY** / *prinos zrna*			**EL** / *duljina klipa*			**RN** / *broj redova zrna*		
	2022	2023	2024	2022	2023	2024	2022	2023	2024	2022	2023	2024
1st.	1.0	-0.5	1.5	7.967	10.154	4.688	18.09	20.88	20.59	16.17	16.35	17.34
G2	1.5	2.0	4.0	5.476	6.997	3.037	17.34	19.88	19.53	19.00	19.00	15.34
G3	2.0	1.5	3.0	6.276	8.786	3.161	19.42	18.03	23.63	15.67	16.65	14.17
G4	2.0	1.0	1.5	6.765	9.061	3.996	18.71	20.34	20.25	16.67	16.15	15.67
G5	0.0	1.0	0.0	5.753	7.819	3.796	20.50	21.71	18.96	17.34	14.50	15.84
G6	1.5	0.0	3.0	6.603	8.356	3.957	18.59	21.79	21.03	16.84	13.65	14.84
G7	-0.5	0.5	2.0	6.582	7.571	3.734	18.42	20.79	20.54	17.00	16.84	17.00
G8	2.0	-1.5	4.5	6.990	7.952	3.618	20.00	18.92	21.09	15.34	16.17	20.17
G9	0.0	1.0	4.5	6.202	6.732	2.903	20.88	20.42	20.00	14.13	15.67	15.67
10st.	1.0	2.0	0.0	6.554	8.310	5.267	19.75	19.75	21.71	17.67	16.00	16.50
G11	1.0	0.0	1.5	6.613	7.772	3.352	20.25	20.46	19.67	14.50	17.65	14.00
G12	1.5	1.5	4.5	6.456	8.042	3.325	19.54	20.00	19.00	15.50	15.50	18.67
G13	1.5	-1.0	2.0	6.654	7.944	3.974	19.13	22.15	18.67	16.00	17.34	15.84
G14	1.0	-1.0	1.5	5.923	8.925	3.636	19.92	20.46	19.21	15.17	13.65	18.67
G15	0.0	1.0	2.0	5.346	7.697	3.408	19.96	20.34	19.75	14.34	15.17	15.84
G16	0.0	1.0	-0.5	7.008	8.478	3.131	18.92	20.13	21.09	16.84	15.50	17.67
G17*	1.0	0.0	2.0	7.448	11.429	3.420	20.17	20.34	20.88	17.00	19.50	15.00
G18	2.0	2.0	1.0	6.964	8.692	3.792	20.63	19.85	20.34	13.67	15.50	16.34
G19	1.5	1.0	2.0	6.529	8.488	3.471	18.50	18.50	20.34	15.67	15.75	16.00
20st.	1.0	1.0	-0.5	7.155	7.530	4.785	19.84	19.92	19.46	14.50	16.84	14.84
G21	1.0	1.5	1.0	6.792	7.663	3.940	21.75	21.34	19.46	16.00	15.17	14.84
G22	1.5	1.0	1.0	6.329	7.319	4.024	20.75	20.71	17.96	14.17	16.34	17.84
G23	0.0	2.0	1.0	7.125	8.430	3.380	23.00	20.63	17.75	13.34	15.30	16.67
G24	1.0	1.0	1.0	7.396	7.849	4.225	20.54	19.75	17.96	15.34	15.67	15.25
G25	1.0	1.0	2.0	6.528	8.553	4.941	19.09	22.14	17.17	17.50	17.35	15.67
Min	-0.5	-1.5	-0.5	5.346	6.732	2.903	17.30	18.00	17.20	13.30	13.70	14.00
Max	2.0	2.0	4.5	7.967	11.429	5.267	23.00	22.15	23.63	19.00	19.50	20.17
Average	1.02	0.76	1.82	6.617	826.17	379.82	19.75	20.37	19.84	15.81	16.13	16.22
STDEV	0.71	0.96	1.42	0.59	0.95	0.60	1.19	0.99	1.38	1.38	1.35	1.47
CV, %	69.99	126.37	78.05	8.91	11.54	15.68	6.03	4.86	6.94	8.72	8.36	9.05

ASI - Anthesis-Silking Interval (days) / *razdoblje metličanja – svilanja (dani);* ***GY - Grain Yield*** / *prinos zrna (t/ha);* ***EL - Ear Length*** / *duljina klipa (cm);* ***RN - Ear Rows Number*** / *broj redova zrna u klipu*

LSD at P=0.05 (2022) – ASI=2.17; GY=1.290; EL=1.73; RN=1.82

LSD at P=0.05 (2023) – ASI=1.17; GY=1.364; EL=1.09; RN=1.50

LSD at P=0.05 (2024) – ASI=2.53; GY=1.366; EL=2.92; RN=1.86

****G17 is used as standard in 2023*** / *G17 korišten je kao standard u 2023. godini.*

Among the traits studied, ASI showed the greatest variability (Table 5). Grain yield (GY) exhibited moderate to intermediate variation over the entire study period. In 2024, the coefficient of variation (CV%) reached its highest value, partially confirming the findings of Vulchinkov (2000) that stress conditions are associated with higher variability. The other two traits, ear length (EL) and number of rows per ear (RN), displayed low variability and were the most stable throughout the study period.

The distribution of genotypes based on Ward's method (1963), which relies on Euclidean distance, is shown in figure 1. It provides a clearer picture with respect to grain yield. The genotypes were grouped into two major clusters. The first cluster included the standard hybrid Konfites (GY = 6.554 t/ha), along with 14 other hybrids. The second cluster encompassed the remaining two standards, P0217 (7.967 t/ha) and Kneja 435 (7.155 t/ha), together with 8 additional entries. The division of genotypes into these two groups can be attributed to differences in grain yield performance (along with its contributing traits) and variation in ASI values. From a breeding perspective, the second cluster appears relatively more promising.

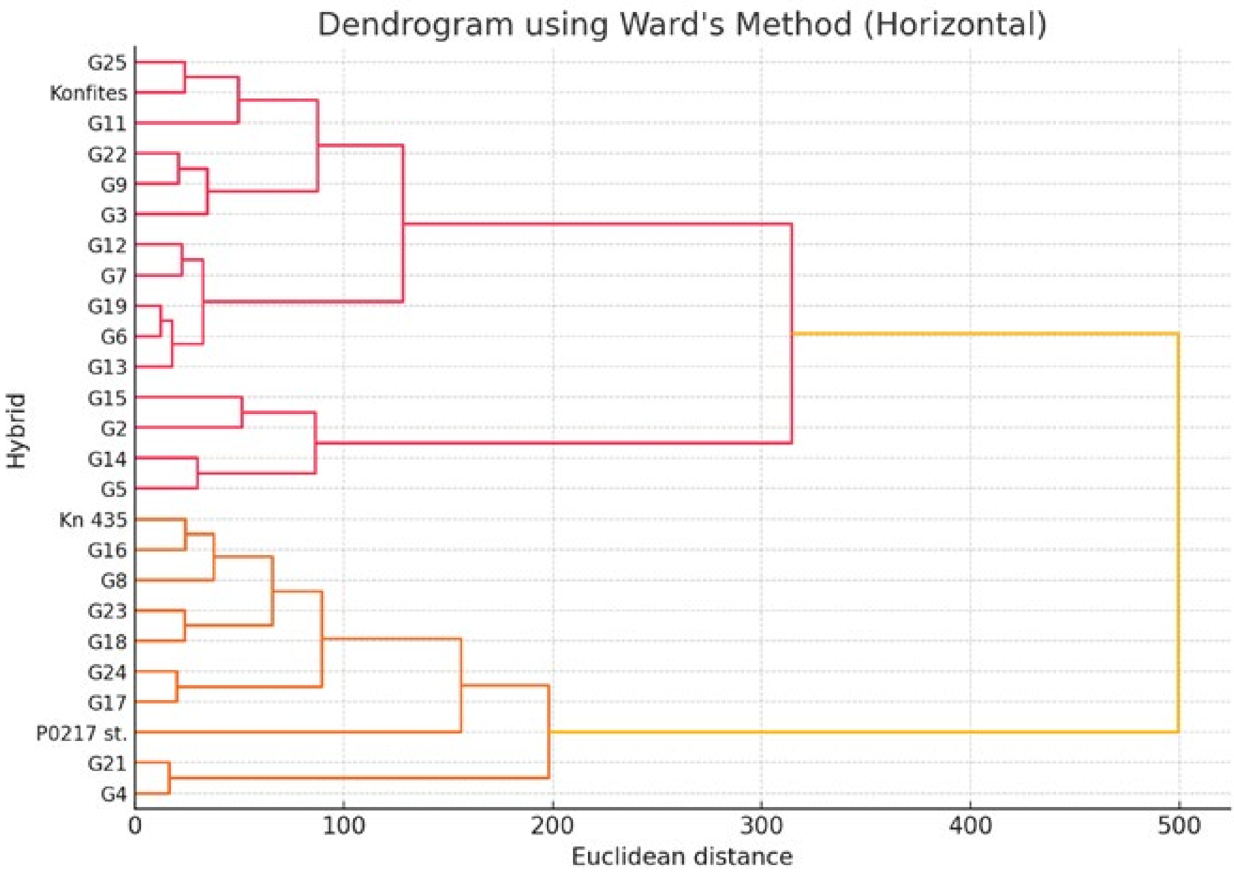

Figure 1. Ward's (1963) cluster analysis dendrogram of 25 maize hybrids tested in 2022.

Grafikon 1. Dendrogram klasterske analize prema Wardu (1963.) za 25 hibrida kukuruza testiranih 2022. godine.

In the following 2023 year, which may be considered the most favorable for maize cultivation during the study period, the LSD value for the anthesis-silking interval was significantly lower (1.17 days), with the trait ranging from –1.5 to +2.0 days (Table 5). This allowed differentiation of two out of the three standards included in the trial (P0937 and P9903), which exhibited ASI values of –0.5 and +1.0, respectively. Combined with their high grain yields (10.154 t/ha and 11.429 t/ha), ear lengths (20.88 cm and 20.23 cm), and number of rows per ear (16.35 and 19.50) in most cases above or close to the maximum recorded values for the year—these two hybrids clearly stand out as a distinct group. This distinction is clearly visible on the dendrogram in Figure 2. The remaining 23 hybrids in the trial are distributed within a larger cluster, which further subdivides into three subclusters, each of which is broken down into smaller subgroups. The evaluation of hybrids follows a gradient from the subgroup containing G9 and G2 (with ASI ~2 and the lowest grain yields for the year) to hybrids like G19 and G6 (ASI = +1.5 and grain yields close to the annual mean).

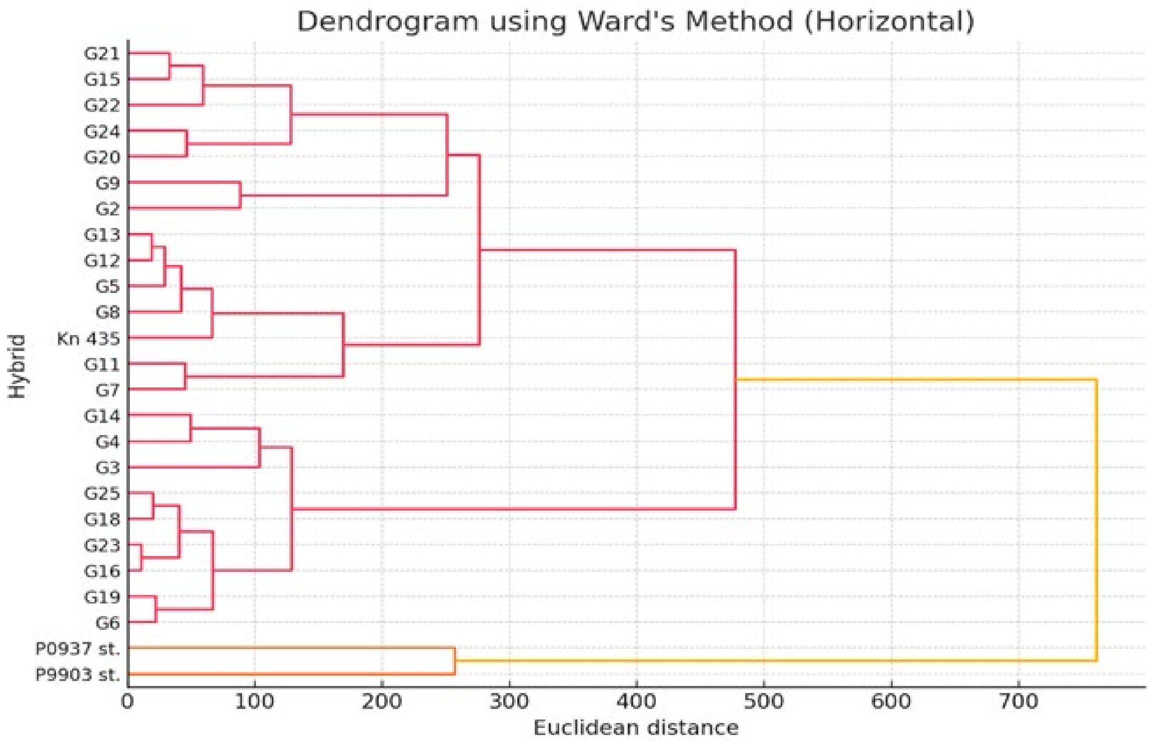

Figure 2. Ward's (1963) cluster analysis dendrogram of 25 maize hybrids tested in 2023.
Grafikon 2. Dendrogram klasterske analize prema Wardu (1963.) za 25 hibrida kukuruza testiranih 2023. godine.

The final year of the study, 2024, was among the worst maize production seasons in Northern Bulgaria, not only within the scope of this research but also in the past two decades overall (Georgieva et al., 2022). This makes it particularly relevant from the perspective of evaluating the ASI period as an indicator of genotype stress tolerance, particularly under drought conditions. Clustering based on the Euclidean distance among genotypes clearly delineates two distinct groups. The first cluster includes 21 hybrids, which further divide into two large subgroups and several smaller ones. A common characteristic among these hybrids is the strong variability in both ASI and grain yield (GY), with ASI values exceeding +1.8 days (the annual average) and grain yields ranging from around the annual mean (3.798 t/ha) down to the minimum recorded (2.903 t/ha). This profile suggests that these 21 hybrids are, to varying degrees, intolerant to the extreme stress conditions of the year – clearly reflected in their very low yield performance (Table 5).

Against the backdrop of the previously mentioned findings, the second cluster from Figure 3 includes four genotypes that stand out due to their greater tolerance to the unfavorable conditions of 2024. Within this cluster, a distinct subgroup is formed by the foreign standard P0023, which is separated from the other three hybrids and shows the greatest Euclidean distance from all genotypes in the entire trial. The hybrid demonstrates the best overall performance in the examined year, with ASI = 0.0 (compared to a trial mean of 1.82 days); the highest grain yield (5.267 t/ha); above-average ear length (EL = 21.71 cm); and number of rows per ear (RN = 16.50);

The remaining three hybrids—G25, Kn 435, and P8904 (the latter being slightly more distant from the other two)—form a subgroup characterized by low ASI values and relatively high grain yield and yield components, indicating their superior adaptation to the stress conditions of the 2024 growing season. Studies involving larger trials, with more tested hybrids and extended over a longer period under diverse environmental conditions, could provide an even clearer and more detailed understanding of how ASI (Anthesis–Silking Interval) can be used as a good indicator of drought tolerance in new maize hybrids (Lima et al., 2023).

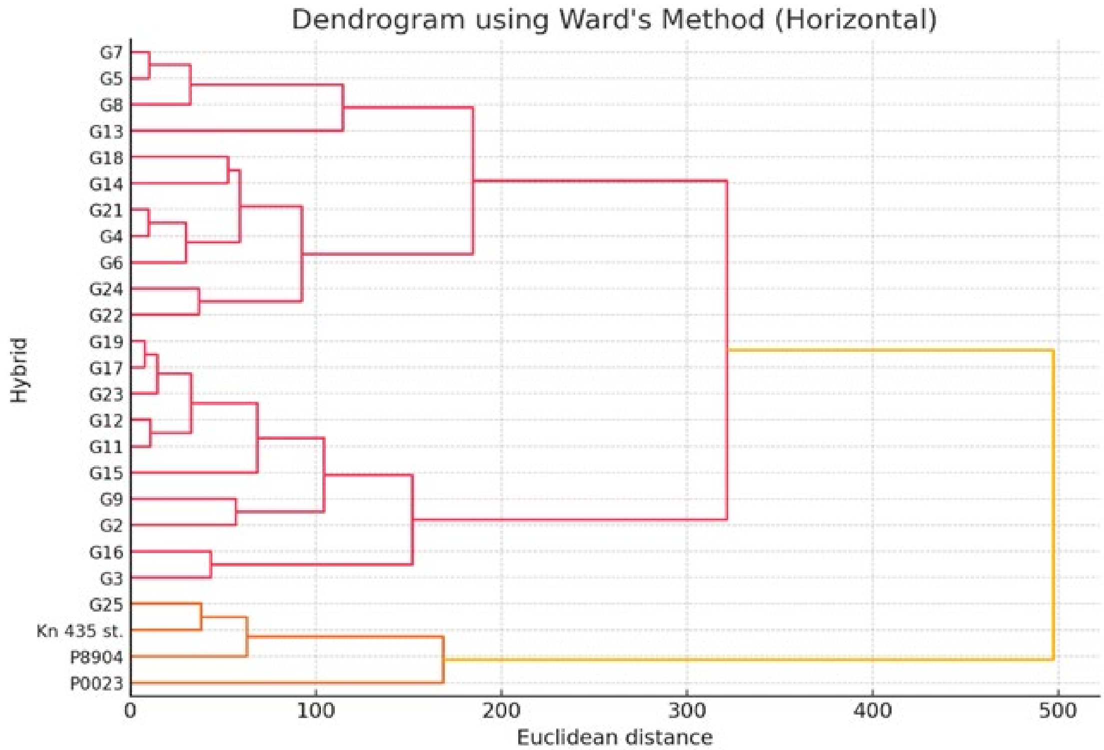

Figure 3. Ward's (1963) cluster analysis dendrogram of 25 maize hybrids tested in 2024.

Grafikon 3. Dendrogram klasterske analize prema Wardu (1963.) za 25 hibrida kukuruza testiranih 2024. godine.

The simple (pairwise) correlations between the traits, broken down by year, are presented in Table 6. The results indicate that the relationships between the studied traits vary considerably in both magnitude and direction, but in nearly 90% of the cases, these correlations are not statistically significant. There are only two notable exceptions. A strong negative correlation between EL and RN in 2022 ($r_{3,4} = –0.655$), which is statistically significant. This suggests an inverse relationship – longer ears tend to have fewer rows and vice versa. A moderate negative correlation between the ASI and GY under the stressful conditions of 2024 ($r_{1,2} = –0.483$), which is also statistically significant. This supports the hypothesis that longer ASI intervals under drought stress are associated with lower grain yield, highlighting the potential of ASI as an indicator of drought susceptibility. In contrast, during the relatively favorable 2023 season, no statistically significant correlations were detected among the studied traits.

Table 6. Joint year-to-year comparison of Pearson's correlation coefficients

Tablica 6. Međugodišnja usporedba Pearsonovih koeficijenata korelacije (2022. – 2024.)

Correlations / *Korelacije*	2022	2023	2024
r1,2	+0.133^{ns}	-0.260^{ns}	-0.483**
r1,3	-0.239^{ns}	-0.203^{ns}	+0.147^{ns}
r1,4	+0.022^{ns}	+0.003^{ns}	+0.177^{ns}
r2,3	+0.114^{ns}	-0.046^{ns}	-0.182^{ns}
r2,4	-0.142^{ns}	+0.190^{ns}	-0.025^{ns}
r3,4	-0,655***	-0.104^{ns}	-0.082^{ns}

ASI (1); GY (2); EL (3); RN (4); ns – not significant / *nije značajno;* ****** - P<0.001; ** - P=0.015***

The results of the calculated multiple correlation coefficients for the studied traits over the entire testing period are presented in the following Table 7. As is well known, this type of correlation (unlike simple or pairwise correlations, which examine the regression between two traits), there is one dependent variable and a combination of multiple independent variables. In our study, grain yield (GY) is considered as a dependent trait, being a composite trait influenced by many secondary traits. The other three traits—ASI, EL, and RN—are treated as independent variables. The multiple correlation coefficient (R) indicates the strength of the combined linear relationship between the independent traits (ASI, EL, RN) and the dependent trait (GY).

Table 7. Joint multiple correlation analysis of studied traits for the three-year period (2022–24)

Tablica 7. Zajednička analiza višestrukih korelacija ispitivanih svojstava za trogodišnje razdoblje (2022. – 2024.)

Multiple Correlation[1] / *Višestruka korelacija*	**2022**	**2023**	**2024**
R	0.210^{ns}	0.332 ^{ns}	0.498**
R^2	0.044 ^{ns}	0.110 ^{ns}	0.248 ^{ns}
β1	+9.38 ^{ns}	−26.41 ^{ns}	−28.35***
β2	+5.90 ^{ns}	−7.91 ^{ns}	−6.41 ^{ns}
β3	−4.72 ^{ns}	+17.36 ^{ns}	+2.99 ^{ns}
P1	0.485 ^{ns}	0.202 ^{ns}	0.024*
P2	0.739 ^{ns}	0.699 ^{ns}	0.582 ^{ns}
P3	0.784 ^{ns}	0.389 ^{ns}	0.798 ^{ns}

[1]***Dependent variable*** / *Zavisna varijabla:* ***Grain Yield (GY); Independent variables*** */Nezavisne varijable:* ***ASI, EL, RN; R – Multiple correlation coefficient*** */ koeficijent višestruke korelacije;* ***R² – Coefficient of determination*** */ koeficijent determinacije;* β ***– Standardized regression coefficients*** */ standardizirani regresijski koeficijenti;* β***1 – ASI;*** β***2 – EL;*** β***3 – RN; P-values (individual significance)*** */ P-vrijednosti (individualna značajnost) ;* ***P1 – ASI; P2 – EL; P3 – RN.***

Over the three-year period (2022–2024), a gradual increase in the value of R was observed. This trend suggests that the predictive power of ASI, EL, and RN on GY improves over time. In 2024, this relationship becomes statistically significant, indicating that under stressful environmental conditions, these traits explain a larger portion of the variation in grain yield. This outcome underscores the importance of integrating multiple physiological and morphological traits when assessing genotypic performance, particularly under adverse growing conditions like those observed in 2024.

In the first year of the study, the correlation between the traits was weak (0.210) and not statistically significant. In 2023, it increased to a moderate level (0.332) but still remained statistically insignificant. In 2024, the correlation reached 0.498 and was statistically significant, which means that nearly 50% of the grain yield (the dependent factor) was affected by the independent factors. The coefficient of determination (R^2), expressed as a percentage, shows what portion of GY is influenced by the variance of the predictor factors and follows the same trend. While in 2022 it was relatively insignificant (4.4%), in 2023 it reached 11%, and in the final year of the study it affected 24.8%, or nearly one-fourth of the yield. The standardized regression coefficient β indicates the strength of the relationship between the independent and the dependent variable. When the corresponding β has a P-value < 0.05, the correlation is considered statistically significant. In our study, this was true for ASI in 2024, which means that the prolonged interval (caused by drought) was the main factor leading to the reduction in grain yield.

CONCLUSION

Based on the conducted study, the following conclusions can be made:

1. The results from both simple (bivariate) and multiple correlations are consistent and confirm that an increase in ASI under drought conditions has a strongly negative effect on grain yield.
2. Cluster analysis arranges genotypes into groups and can be used as a rapid assessment method for identifying optimal combinations of the studied traits within a single genotype.
3. Selection for a shorter anthesis–silking interval can be applied in tandem selection for drought tolerance.

REFERENCES

1. Abera, N., Odong, T., & Kasozi, L.C. (2021). Phenotypic Diversity and Correlation Coefficient Analysis of Open Pollinated Maize Varieties in Uganda. *Global Journal of Agricultural Research Vol.9*, No.1, pp.36-47, 2021 Print ISSN: ISSN 2053-5805(Print), Online ISSN: ISSN 2053-5813(Online)
2. Ao, S., Russelle, M. P., Varga, T., Feyereisen, G. W., Coulter, J. A. (2020). Drought tolerance in maize is influenced by timing of drought stress initiation. *Crop Science, 60*, 1591–1606. https://doi.org/10.1002/csc2.20108
3. Bassetti P. & Westgate M.E. (1993a). Emergence, elongation, and senescence of maize silks. *Crop Science 33*, 271–275.
4. Bassetti P. & Westgate M.E. (1993b). Water deficit affects receptivity of maize silks. *Crop Science 33*, 279–282.
5. Bolaños, J. and Edmeades, G.O. (1996). The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. *Field Crops Research, 48* (1), pp.65-80.
6. Bruinsma, J. (2017). World agriculture: towards 2015/2030: an FAO study. *Routledge*.
7. Edmeades, G.O., Bolaños, J., Elings, A., Ribaut, J., Bänziger, M. & Westgate, M.E. (2000). The Role and Regulation of the Anthesis-Silking Interval in Maize. In *Physiology and Modeling Kernel Set in Maize* (editors: M. Westgate, K. Boote, D. Knievel and J. Kiniry). https://doi.org/10.2135/cssaspecpub29.c4
8. Elmore, Roger W. (2012) "Stress, Anthesis—Silk Interval and Corn Yield Potential". *Integrated Crop Management News. Paper 219*. http://lib.dr.iastate.edu/cropnews/219

9. Fuad-Hassan, A., Tardieu, F. & Turc, O. (2008). Drought-induced changes in anthesis-silking interval are related to silk expansion: a spatio-temporal growth analysis in maize plants subjected to soil water deficit. *Plant, Cell & Environment, 31*: 1349-1360. https://doi.org/10.1111/j.1365-3040.2008.01839.x
10. Genchev G., E. Marinkov, V. Yovcheva, A. Ognyanova (1975). Biometric methods in plant breeding, genetics and selection. *Zemizdat*, Sofia.
11. Georgieva, V., Kazandjiev, V., Bozhanova, V., Mihova, G., Ivanova, D., Todorovska, E., Uhr, Z., Ilchovska, M., Sotirov, D. and Malasheva, P. (2022). Climatic Changes – A Challenge for the Bulgarian Farmers. *Agriculture, 12 (*12), p.2090.
12. Kahiu, N., Jerono, C. and Muchira, C. (2013). Anthesis to Silking Interval Usefulness in Developing Drought. *JRA*, 2013, 1(5): 84-90 DOI: 10.12966/jra.08,03.2013
13. Kim, H. C., Moon, J.-C., Kim, J. Y., Song, K., Kim, K.-H., & Lee, B.-M. (2017). Evaluation of Drought Tolerance using Anthesis-silking Interval in Maize. *Korean Journal of Crop Science*, 62(1), 24–31. https://doi.org/10.7740/KJCS.2016.62.1.024
14. Lima, D. C., de Leon, N., & Kaeppler, S. M. (2023). Utility of anthesis–silking interval information to predict grain yield under water and nitrogen limited conditions. *Crop Science, 63*(1), 151-163.
15. Parent, B., Leclere, M., Lacube, S., Semenov, M. A., Welcker, C., Martre, P., & Tardieu, F. (2018). Maize yields over Europe may increase in spite of climate change, with an appropriate use of the genetic variability of flowering time. *Proceedings of the National Academy of Sciences, 115*(42), 10642-10647.
16. Santos, Á. D. O., Pinho, R. G. V., Souza, V. F. D., Guimarães, L. J. M., Balestre, M., Pires, L. P. M., & Silva, C. P. D. (2020). Grain yield, anthesis-silking interval and drought tolerance indices of tropical maize hybrids. *Crop Breeding and Applied Biotechnology*, 20(1), e176020110.
17. 16. Tokatlidis, I.S. and Koutroubas, S.D. (2004). A review of maize hybrids' dependence on high plant populations and its implications for crop yield stability. *Field Crops Research, 88*(2-3), pp.103-114.
18. Tsimba, R., Edmeades, G. O., Millner, J. P., & Kemp, P. D. (2013). The effect of planting date on maize: Phenology, thermal time durations and growth rates in a cool temperate climate. *Field Crops Research, 150*, 145-155.
19. Valkova, V. (2012). Study of heterosis and seed production of a new generation of hybrids at the Maize Institute - Knezha. Doctoral Dissertation, Knezha.
20. Vulchinkov S. (2000). Study of genotype-environment interaction in self-pollinated lines and hybrids of maize / Zea mays L./. PhD Thesis. Knezha.
21. Vulchinkov, Z., & Vulchinkov, S. (2023). Variation and Correlations between Characteristics in Maize Hybrids from Different Vegetation Groups. *Journal of Mountain Agriculture on the Balkans, Vol. 26*, Issue 4, pp. 180–200
22. Vulchinkov, Zh & Hristova-Cherbadzhi, M. (2025). Effect on the plastid pigments content and grain yield in two maize hybrids following treatment with microbial fertilizers of the "Microbtima" group. *Bulgarian Journal of Crop Science* – In Press
23. Ward J.H., (1963). Hierarchical grouping to optimazed an oljective function. *Journal of the American Statiatical Association*. 58, 236-244

INTERVAL IZMEĐU METLIČANJA I SVILANJA TE NJEGOVA POVEZANOST S ODREĐENIM KOMPONENTAMA PRINOSA KOD HIBRIDA KUKURUZA IZ SREDNJE RANE FAO GRUPE

SAŽETAK

U ovome istraživanju ispitana je varijabilnost, korelacijske veze i grupiranje između četiriju agronomski važnih svojstava kukuruza: razmaka između metličanja i svilanja (ASI), prinosa zrna (GY), duljine klipa (EL) i broja redova zrna u klipu (RN). Ukupno je evaluirano 75 hibrida kukuruza iz srednje rane grupe dozrijevanja (FAO 400–500), testiranih u pokusima konkurentnih sorata tijekom trogodišnjega razdoblja (2022. – 2024.). Cilj istraživanja bio je procijeniti značenje razdoblja ASI-ja i njegov utjecaj na prinos zrna. Dobiveni rezultati pokazuju snažno negativan učinak produljenoga ASI-ja (do 5 dana) na prinos zrna u 2024. godini, što je potvrđeno analizama jednostavne i višestruke korelacije. Klasterska analiza, provedena Wardovom metodom (1963.) i prikazana u obliku dendrograma, omogućila je grupiranje hibrida te se pokazala korisnim alatom za procjenu optimalne kombinacije ispitivanih svojstava unutar pojedinoga genotipa. Selekcija hibrida s kratkim ili dapače negativnim razmakom između metličanja i svilanja može se koristiti kao neizravna metoda odabira na tolerantnost prema suši, poznata i kao tandem-selekcija.

Ključne riječi: hibridi kukuruza, ASI, prinos zrna, jednostavna i višestruka korelacija, klasterska analiza

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