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RESPONSE OF MAIZE BREEDING TO CLIMATE CHANGE

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Abstract

Maize is the species with highest world production and the most widely planted agricultural crop. Breeders and the agricultural community around the world will have to expand the capacity of current breeding programs to increase yield potentials in the conditions of climate changes. In the paper the effect of key factors such warmer temperatures, changes in rainfall and higher concentrations of CO2 on the productivity of maize were reviewed based on the literature. The most sensitive stages to drought were shown. Breeding tools to mitigate unfavorable effect of climate changes on grain yield of maize were reviewed. Breeding program achievements of the Maize Research Institute Knezha, Bulgaria was shown. New hybrids Kneja 461 and Kneja 561 due to their drought tolerance were found as more productive comparing to the standards Kneja 435 and Kneja 509 in new conditions. Future prospects of the breeding of maize were shown as development of maize varieties resistant to high temperatures; selection and improvement of maize varieties capable of maintaining growth and productivity under changed environment, ect.

Key words: *climate change, drought, maize.*

INTRODUCTION

Maize is the species with highest world production and as the most widely planted agricultural crop plays an irreplaceable role in ensuring food security (Ranum et al., 2014). Given the rapidly expanding global population, addressing the food security needs and the rising demand for food and also feed has become increasingly crucial (Ifeanyi, 2024) Climate change (in particular increased temperatures and drought) is acutely related to food security of humans, which strongly depends on the growth of crops as maize, wheat, and rice.

When considering the net impacts of climate on food production, we need to consider three key factors: warmer temperatures, changes in rainfall (which can cause too much, or not enough, water) and higher concentrations of CO_2. Meteorological factors during the growing season of maize are of big importance for the yield. In recent decades, noticeable climate changes have been observed, expressed in an increase in the active temperature sum and uneven precipitation (Huang et al., 2015; Qiao et al., 2025).

Grain maize is projected to be the most affected crop by climate change in Europe. According to Tesfaye et al. (2018) under fully irrigated conditions, substantial yield reductions are estimated for most producing countries, being more severe in Southern Europe in all scenarios. Maize loses around 15% of its global yield due to drought stress (Tesfaye et al., 2018). Therefore, to prevent these yield losses and to maintain maize yields in dry regions, the drought tolerance of maize must be improved. An important aspect related to weather conditions is the crop yield. Yield can vary from year-to-year, as a result of ever changing natural conditions, especially the weather. Identifying high-yielding and sustainable genotypes in diverse environments has been a constant challenge for plant breeders worldwide.

Create new varieties with increased resistance to drought and heat stress with high yield potential and stable productivity over the years, a result of mitigating the negative impact of adverse weather conditions. Considering all of the above our work aimed at to assess the response of maize hybrids to meteorological conditions vis. temperature and rainfall in a given location.

MATERIALS AND METHODS

The experiment was carried out at the experimental field of the Maize Research Institute - Knezha, Bulgaria under non-irrigated conditions during four consequently years (2020- 2023). Four hybrids from two maturity groups were tested as follows: mid-early hybrids (FAO 400-500) Kneja 435 and Kneja 461, and mid-late hybrids (FAO 500-599) Kneja 509 and Kneja 561. A block method was used, 4 replications, the size of the experimental plot was 10 m2 and the density of 5300 plants/da. The soil type was typical chernozem. The standard technology of growing of maize was applied. Meteorological conditions (rainfall and daily average temperature of growing seasons were recorded.

In addition, the meteorological conditions for long term period (1991-2020) was shown. Hydrothermal Coefficient (HTC) was calculated for the reproductive stage (sum of precipitation and accumulated sum of daily temperature from last decade of June and all days of July) for each year of study. To calculate the Hydrothermal coefficient the next formula as suggested Selyaninov was applied: HTC= Σ x / Σ t x 10; where Σ x and Σ t – accordingly sum of precipitations and temperatures in the period. Interpretation of the hydrothermal coefficient according to Selyaninov was based on the following: HTC from 1.0 till 2.0 – humidity is sufficient; HTC > 2.0 – immoderately humid; HTC < 1.0 – insufficient humidity; HTC from 1.0 till 0.7 – dry; HTC from 0.7 till 0.4 – very dry. The grain yield was calculated in kg/da and it was reported at moisture content of 14%. Factorial regression was performed to obtain a biological explanation of the hybrid, environment, and hybrid - environment interaction for the yield.

Statistical analysis of the experimental data using Anova without and with replication processing was performed using the SPSS 20.0 software product for Windows.

RESULTS AND DISCUSSIONS

The meteorological conditions comprising the growing season of maize over a long-term period (30 years) are presented in Figure 1. From the data, it can be seen that the mean daily temperature increases gradually from April to July and August. The most significant temperature difference was found between April and May (4.1°C), while between May, June and July it was about 3°C. The highest monthly mean daily temperatures were recorded in the typically summer months of July and August, with values very similar.

Monthly rainfall totals increase from the beginning of the growing season in April to July, again with the most significant difference between April and May (about 14 mm), while between May, June and July (65, 67 and 70 mm), the difference ranged from 2 to 5 mm. A significant decrease in the rainfall total for this long-term average period was recorded in August (37 mm), with a total for the growing season of 289.0 mm.

For the 2020-2023 study period, meteorological conditions during the maize growing season by year are presented in Figure 2. A gradual increase in mean daily temperature occurs from April to July and August. In May and June the temperature was above 16°C and above 20°C respectively, with higher values of 17.4°C and 21.6°C only in 2022. Comparing the differences of the monthly mean daily temperatures of April and May over the long-term period with those of the study years, the differences were found to increase from 4.1°C to 5.0°C, 6.0°C, 6.2°C and 5.0°C for 2020, 2021, 2022 and 2023, respectively. This accelerated warming at the beginning of the growing season in four consecutive years is indicative of a change in the environmental conditions during the vegetative stage of crop development. Temperatures were found highest in July, with only 2020 recording a higher value for August (23.5°C). The high temperatures in July coincide with the reproductive stage of maize development, which can have an extremely negative effect on the yield as suggested by Shiduo et al. (2024) also.

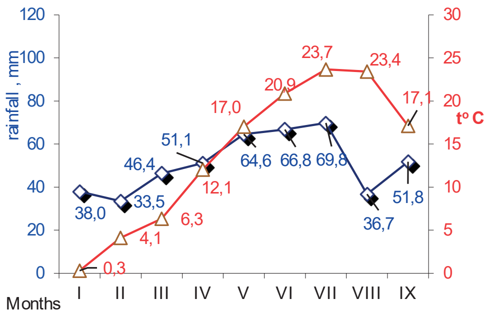

Figure 1. Meteorological conditions including the growing seasons of maize for the long term 30 years period 1991-2020

The precipitation was very irregularly distributed by months. The highest quantities average for the period were registered in May and June and the lowest in July (Table 1).

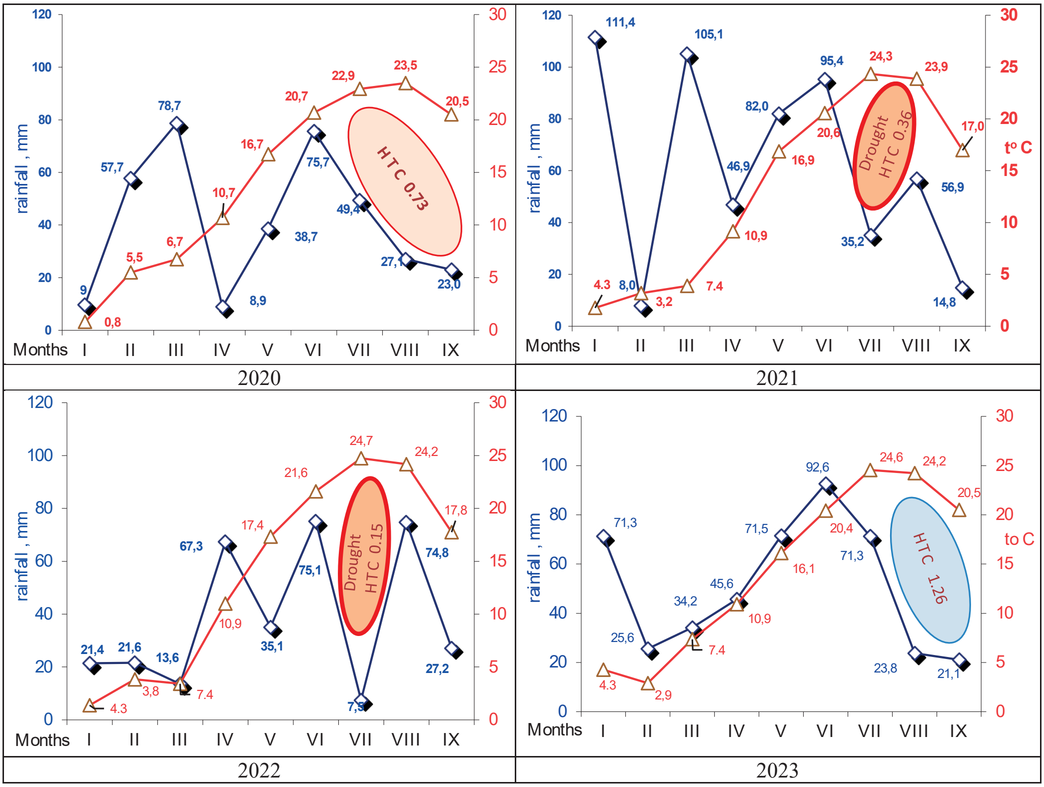

Figure 2. Meteorological conditions during the growing seasons of maize for the period 2020-2023

The total precipitation amounts for the growing season fluctuated by year. The smallest amount was recorded in 2020 being 26% less than the average for the period. The highest precipitations as a sum were recorded during years 2021 and 2023, exceeding the average for the period by 17 and 13%, respectively.

Table 1. Precipitation for the growing season by years, mm

Year/months	2020	2021	2022	2023	Average
IV	8.9	46.9	67.3	45.6	42.2
V	38.7	82.0	35.1	71.5	56.8
VI	75.7	95.4	75.1	92.6	84.7
VII	49.4	35.2	7.5	71.3	40.9
VIII	27.1	56.9	74.8	23.8	45.7
∑precipitation	199.8	316.4	259.8	304.8	270.2
HTC	0.73	0.36	0.15	1.26	

Undoubtedly, precipitation is the most important factor influencing on the maize grain yield (Huang et al., 2015). How this precipitation both by month and as total sum, influenced the maize growing and development and also the yield of grain is not so clear. To clarify the importance of precipitation, we calculate the hydrothermal coefficient as suggested by Selyaninov (1928) for the main stages of the reproductive period of maize. For the location of Knezha this period begins relatively from June 20th and continues throughout the whole month of July. The calculation of the ratio of the average daily temperature sum and the precipitation through HTC characterizes in more detail the conditions in which this important reproductive stage of development of maize occurs (Qiao et al., 2025). It is evident from the HTC calculated values by year that they do not correspond to the rainfall amounts during the growing season. For example, the 2020 growing season has the least amount of rainfall (199.8 mm), but this during the reproductive stage together with the temperature amount formed a coefficient of 0.73, while the 2021 growing season has the highest amount of rainfall (316.4 mm), the HTC coefficient was twice as low (0.36). The lowest hydrothermal coefficient for the reproductive stage was recorded in 2022 (0.15), despite the close precipitation amount to the average for the growing season (259.8 mm). This is mainly due to the scanty rainfall in July of 2022. The highest value of HTC was recorded in 2023 due to significant rainfall during the last ten days of June and the whole month of July.

Weather conditions affect the formation of grain yield of maize. The reported grain yields of maize hybrids and the values of the hydro-thermal coefficient are presented in Table 2.

Table 2. Grain yield from maize hybrids (kg/da) and HTC for the reproductive stage of the plants

	Hybrid \ Year	2020	2021	2022	2023	Average	% to Av,
FAO 400	Kneja 435	931.3	869.9	857.3	1007.9	916.6	99.5
	Kneja 461	911.4	901.6	898.5	992.4	925.9	100.5
	Average	921ş3	885.7	877.9	1000.1	921.3	
	LSD 0.05%	Ns	20.3	25.5	Ns	Ns	
FAO 500	Kneja 509	972.4	958.2	910.4	1003.2	961.1	96.9
	Kneja 561	1040.9	1004.2	977.1	1070.0	1023.1	103.1
	Average	1006.7	981.2	943.8	1036.6	992.1	
	LSD 0.05%	Ns	Ns	25.5	Ns	49.3	
	HTC*	0.73	0.36	0.15	1.26		

*Hydrothermal Coefficient

In each maturity group, two hybrids created at the Maize Institute - Knezha have been tested, one established in practice for decades (Kneja 435 and Kneja 509) and one new hybrid developed in recent years (Kneja 461 and Kneja 561).

The grain yields of all four hybrids varied according to the weather conditions during the growing seasons of each year. Tomov et al. (1995) found that in years of extreme drought, grain yield of maize was very low. On average, the lowest yields were obtained in 2022 (877.9 kg/da) for the FAO 400 maturity group and 943.8 kg/da for the FAO 500 maturity group, respectively. The grain yields obtained in the experimental years 2020 and 2021 were relatively similar, while the highest yields were obtained in 2023. This variation over the study period is consistent with the HTC for the maize generative period by year. Comparing the yields of the hybrids in the FAO 400 maturity group, there was evidence of an excess of yields of Kneja 461 in the years with the most pronounced drought during the generative period, namely in 2021 and especially in 2022, with HTC of 0.36 and 0.15, respectively. On average over the period, no differences were found between the yields of the Kneja 435 and Kneja 461 hybrids due to similar yields in 2020 and 2023.

For the FAO 500 maturity group hybrids, it can be seen that hybrid Kneja 561 has the highest grain yields in all years, but only in 2022 the HTC has a value of 0.15. The difference for 2022 and the average over the study period is statistically significant.

Considering the importance of maize and its cultivation potential worldwide and in Bulgaria, this crop's yield sustainability was studied in previous research. Genotype × environment interaction (GEI) is responsible for genotype sustainability characteristics. One of the usual exacting effects in plant breeding development is to dissect the genotype × environment (GE) interaction correctly. Genotype × environment interaction adjusts the reasonable grain yield of genotypes in diverse environments and makes it hard to select the better ones (Miah et al., 2016).

The results of the Anova with replications analysis conducted for the hybrids in the FAO 400 maturity group showed that the year of cultivation factor with specific weather conditions influenced the results with a 71.8% part (Table 3). The maize hybrid factor was insignificant due to the close yields obtained in the first and last year, and the average over the period.

Our results are in agreement with those of Romay et al. (2010). Similar to ours were the findings of Sárvári and Pepó (2014).

Considering only the yields obtained in 2021 and 2022, which had a certain drought during the generative period of maize (HTC - 0.36 and 0.15), the influence of the hybrid factor was found to be significant and that of the year insignificant (Table 4). This leads us to conclude that the new hybrid Kneja 461 in years with pronounced drought during the generative period has increased resistance, and in such conditions was less affected by adverse abiotic factors and provides stable yield.

Wilhelm et al. (2004) for long time period also suggested insufficient summer precipitation were major constraints for maximum maize yield. The same is for the studies of Malone et al. (2009).

Table 3 Anova with replications for the Kneja 435 and Kneja 461 hybrids for the period 2020-2023

Source of Variation	SS	df	MS	F	P-value	F crit	Factor	%
Year	75014	3	25004	26.3	9,1E-08	3,00	Year	71.8
Hybrid	707	1	707	0.7	0.397	4.26	Hybrid	0.7
Interaction	5995	3	1998	2.1	0.126	3.00		
Within	22778	24	949				Error	27.5
Total	104495	31						

Table 4 Anova with replications for the hybrids Kneja 435 and Kneja 461 for 2021 and 2022

Source of Variation	SS	df	MS	F	P-value	F crit	Factor	%
Hybrid	5340.0	1	5339	29.8	0.001	4.74	Hybrid	68.4
Year	240.4	1	240	1.3	0.269	4.74	Year	3.1
Interaction	87.0	1	86.5	0.4	0.500	4.74		
Within	2145.6	12	178.8				Error	28.6
Total	240.4	1	240.4	1.3	0.269	4.747		

The results of the ANOVA with replications analysis carried out for the hybrids in the FAO 500 maturity group showed that the year of cultivation factor with the specific weather conditions and the hybrid affected the results, albeit by a lower percentage, 37.7 and 31.2%, respectively (Table 5).

Table 5 Anova with replications for the Kneja 509 and Kneja 561 hybrids for the period 2020-2023

Source of Variation	SS	df	MS	F	P-value	F crit	Factor	%
Hybrid	37172.5	3	12390.8	9.88	0.00198	3.009	Year	37.7
Year	30740.7	1	30740.7	24.51	4,7E-05	4.260	Hybrid	31.2
Interaction	686.5081	3	228.8	0.18	0.907	3.009		
Within	30093.8	24	1253.9				Error	31.2
Total	98693.5	31						

When comparing the yields formed in years with the most pronounced drought during the reproductive period of maize (2021 and 2022), applying Anova with replications, a significant influence of the hybrid factor (40.0%) and a lesser influence of the year was found, as the calculated HTC had similar values of 0.36 and 0.15, respectively (Table 6).

Table 6 Anova with replications for the Kneja 509 and Kneja 561 hybrids for 2021 and 2022

Source of Variation	SS	df	MS	F	P-value	F crit	Factor	%
Hybrid	12702.9	1.0	12702.9	11.75	0.005	4.747	Hybid	40.0
Year	5612.9	1.0	5612.9	5.19	0.042	4.747	Year	17.7
Interaction	429.5	1.0	429.5	0.39	0.540	4.747		
Within	12968.1	12.0	1080.7				Error	42.2
Total	31713.4	15.0						

From the obtained results of this analysis, we can conclude that the newly developed hybrid Kneja 561 was less affected by the occurrence of drought during the reproductive period compared to Kneja 509 and consequently the obtained yields are more stable in years with such weather conditions.

Maize breeding in response to climate change aims to develop maize varieties that can reduce negative impacts on agriculture such as high temperatures, droughts. Kim and Lee (2023) suggested the factors for consideration in maize breeding in response to climate change. According to them these factors are high-temperature tolerance, drought tolerance, response to low precipitation. For this purpose should be developed maize varieties resistant to high temperatures; to select and improve maize varieties capable of maintaining both growth and productivity.

The obtained yields of the new hybrids Kneja 461 and Kneja 561 in years with pronounced droughts during the reproductive period of maize, which are superior to the established in practice Kneja 435 and Kneja 509, were the result of targeted selection in the direction of resistance to water deficit stress.

CONCLUSIONS

For the hybrids of maturity group FAO 400 in years with drought during the generative period of maize, the influence of the hybrid factor was found significant (68.4%) and insignificant of the year. The new hybrid Kneja 461 showed increased resistance, it was less affected by adverse abiotic factors and provided stable yield.

For hybrids of maturity group FAO 500 in years with pronounced drought during the generative period of maize, the influence of the hybrid factor was found (40.0%) and less influence of the year (17.7%). The newly developed hybrid Kneja 561 was less affected by drought compared to Kneja 509 and formed a more stable yield.

We can recommend since the environment very much influences genotypes, locations, and years, performance related to the stability of genotypes is a prerequisite and must carry out in different environments over different years in a given location.

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