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EVALUATION OF THE YIELD, MINERAL AND LUTEIN CONTENT OF SWEET MAIZE (ZEA MAYS. L. CONVAR SACCHARATA KOERN)

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Abstract

Heat stress is a severe abiotic stress factor, affecting both the quantity and quality of yield. Sweet maize is a priority source of healthy food worldwide and its production is increasing each year. The aim of this research is to study two sweet maize hybrids adapted to changing environmental conditions to best preserve their production quantity and quality. In an experiment set up at the Experimental Centre at the University of Debrecen, the yield and essential nutrient content of two different genotype super sweet maize hybrids were investigated in two different crop years. Quality parameters were determined under laboratory conditions from grain samples taken at harvest. The obtained results showed that plant height, the ear height on the stem, biological yields and quality were significantly influenced by the given crop year. The mineral, carotenoid and sugar contents of sweet maize were determined in the University's laboratory. It was demonstrated that heat stress significantly reduces yield and the quality parameters of sweet maize hybrids. It was shown that the heat stress effect is greater than that of the difference between sweet maize genotypes. Therefore, stress effects should be analysed for each genotype. It was shown that genetic background and environmental conditions, especially heat stress, together determine the quantity and quality of the harvested yield. The obtained laboratory results show that mineral content changes significantly under heat stress. It was revealed that heat stress significantly reduces the valuable lutein content. A close correlation between zeaxanthin and lutein content was observed in sweet maize hybrids. It is a new finding that the decrease in lutein and zeaxanthin was similar under heat stress, the amount of which was shown to be hybrid-specific. The performed analyses showed that both hybrids showed a decrease in sugar content under heat stress, with different rates of sugar loss.

Key words: sweet maize, heat stress, lutein content, sugar content

INTRODUCTION

The projected population growth by 2050 is expected to increase the demand for natural resources that provide food (OECD, 2012).

The importance of sweet maize as a healthy food is growing worldwide (Santos et al., 2014). Production is increasing year by year thanks to precision irrigation farming (Kara and Atar, 2013) and breeders' use of high quality sweet maize hybrids. According to Saalem, 2013, the right choice of sweet maize hybrids is an important factor in cultivation. Adverse environmental factors may reduce the yield and quality of the crop (Nemeskéri et al., 2019). It is very important to select the most ideal sweet maize hybrids for the production purpose (fresh consumption, industrial purposes (Wu et al., 2019).

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According to Zhao et al., 2019, genetic ability and morphological traits have a great influence on maize yield. Results from other research have also shown that sweet maize genotype, crop year effect and the interaction of the two determine the yield and quality of sweet maize (Sridic et al., 2016). According to Mand et al., 2010, the professional level of technology contributes greatly to successful production. Continuous monitoring of the grown crops using modern precision farming methods reduces environmental stress and enables sustainable farming (Nagy and Nagy, 2018; Nyéki et al., 2020). In their studies, Nagy et al., 2021, found that professional precision replenishing of soil organic and inorganic matter increases the amount of minerals available for uptake by plants.

Kandil et al., 2020, also demonstrated that professional nutrient supplementation can increase plant health. According to Illés et al., 2021, in order to overcome environmental stresses, in addition to the correct choice of genotypes, it is necessary to provide adequate nutrient supply to meet the needs of the given genotype, as supported by the research results of Széles and Huzsvai, 2020; and Rácz et al., 2021.

According to Xie et al., 2016, sweet maize quality varies with temperature during dry matter gain. The amount of minerals is the result of the interaction between genetic and environmental factors (Torres-Martinez et al., 2019). Ionic forms of the elements K, P and Ca play a crucial role in many plant functions such as energy production or intracellular communication (Salt et al., 2008). Bangar et al., 2017, demonstrated a positive correlation between high Fe and high carotenoid concentrations. Schlegel and Havlin, 2017, investigated the response of maize to N and P fertilisation in a fifty-year continuous irrigation long-term experiment, their experiments showed a strong positive interaction between N and P, demonstrating the beneficial effect of adequate fertilisation compared to no fertilisation.

Continued global temperature increases and decreases in water supply result in yield losses. Studies have shown that a 1.5 °C increase in global average temperature can hamper food security, agriculture and health (Nangombe et al., 2018, 2019; Sun et al., 2019). Heat stress is one of the most important abiotic stressors limiting crop production. An increase in temperature above a critical value is enough to cause irreversible damage to both growth and development (Wahid, 2007). For maize stands, the appropriate temperature for dry matter incorporation is about 25°C, a 1°C increase in temperature can reduce grain yield by 3-4% (Cairns et al., 2012). Heat stress after flowering results in smaller ears and low yields (Farooq et al., 2011).

According to several researchers, maize plant height, biomass, kernel number and harvested yield are reduced by heat stress during grain filling

(Cicchino et al., 2010; Rattalino Edreira and Otegui, 2012). In recent years, heat stress has led to the widespread appearance of abnormal ears, reducing yields (Ortez et al., 2019). According to Ortez et al., 2022, ear deformity in sweet maize is a response to stress effects on the plant. In field experiments, it was found that maize plants with abnormal ears tend to have fewer and poorer quality maize kernels (Elmore et al., 2016). Also, Fahad et al., 2017, found that heat stress has negative effects on plant development and biochemical processes. Heat stress reduces the incorporation of dry matter already after flowering, contributing to leaf senescence and causing yield loss (Yang et al., 2017).

According to Zandalinas et al., 2018, breeding maize hybrids is the key to maintain the potential for yield increase for more satisfactory drought and heat stress tolerance. According to Chukwudi et al., 2021, in their research, different maize varieties can produce different yields under combined heat and water stress conditions, and this should be taken into account to guarantee high yield. Heat stress damages plant leaves and thus stomatal capacity (Muluneh et al., 2020). Stress tolerance relies on the activation of antioxidant systems that can neutralise reactive oxygen species produced in response to stress, preventing cell damage (Barnabás et al., 2008). The quality of sweet maize is also determined by the antioxidants, i.e. carotenoids, present in the plant (Illés et al., 2021). Lutein and zeaxanthin are the most important carotenoids in 65 % of sweet maize kernels. β-carotene and β-cryptoxanthin at similar concentrations account for about 6 % of total carotenoids (Baseggio et al., 2020).

Temperature has a vital impact on plant growth and development, and heat stress is a serious threat to agricultural productivity and food security.

MATERIAL AND METHOD

The experiment presented in this paper was carried out on chernozem soil at the Research Centre of the Faculty of Agriculture, Food Science and Environmental Management of the University of Debrecen. In this research, analyses were performed with the super sweet maize hybrid H1 (DESSERT) with 79 days of medium maturity and the super sweet maize hybrid H2 (MESSENGER) with 85 days of medium maturity in the growing seasons 2020 and 2021. The two-factor small plot field experiment had a strip-plot design and four replications. Prior to the two examined growing seasons, the preceding crop was sweet maize and Laudis 5 l/ha was applied as herbicide. In 2020, the amount of nutrients applied was 80 kg N/ha, 21 kg CaO/ha and 15 kg Mg/ha. Date of sowing: 22.05, emergence: 05.06, tasseling: 19.07, silking: 21.07, harvesting: 17.08. In 2021, the amount of nutrients applied was 90 kg N/ha, 23 kg CaO/ha, and 16 kg Mg/ha. Date of sowing: 29th April, emergence: 14th May, tasseling: 14th July, silking: 17th July, harvesting:

20th August. 104 mm of irrigation water applied using drip irrigation system in the cropping year of 2020, and 214 mm in 2021.

Using an agrometeorological weather station, air temperature, humidity, wind speed, solar radiation, precipitation, soil surface temperature (+ 10 cm), and soil temperature (at depths of 6 and 20 cm) were measured every 10 minutes. During the critical period of sweet maize development (from 15th July), the performed measurements were extended to include maize stand surface temperature with infrared thermometer, PAR global and reflex, air temperature and humidity gradient (above the stand at 0.5 and 3 m), 3D sonic anemometer, air humidity, and carbon dioxide concentration measurements with LI 850.

It was found that in the autumn-winter of 2019-2020 (October to March) prior to the growing season showed a positive anomaly (+ 51 mm) with continuous variability compared to the climate average (1991-2020). The autumn-winter period of 2020-2021 was more balanced, with 35 mm precipitation above the multi-year average. In general, the autumn-winter months preceding the growing seasons were characterised by warmer than average temperatures in the two examined years, combined with rainfall amounts above the 30-year average. In the spring (April and May) of both years. In the 2020 growing season, lower than average rainfall was measured. Night-time minimum temperatures were almost below 10 °C, often 5 °C or below. Suboptimal temperature conditions adversely affected the germination of sweet maize hybrids, as well as the early development period. In terms of monthly amounts of irradiation, the performed examinations showed significant differences compared to the 30-year average for May and April, with opposite signs (2020: 16.5 %, 2021: - 9.4 %). In the two examined years, agrometeorological conditions did not differ significantly (Tables 1-2).

Table 1

Average monthly temperature of the growing season (°C) (Debrecen, 2020-2021)

Growing season		**2020**	**2021**
	Climate Avg. (1991-2020)	**Avg.**	**Avg.**
Apr	11.8	9.1	10.8
May	16.7	15.1	14.0
June	20.2	22.6	19.7
July	21.8	24.6	21.0
Aug	21.7	21.0	22.6
Sept	16.5	16.4	18.2

Avg = average

Statistical evaluation of the results was performed with R.3.2.4., using analysis of variance and Fischer's LSD test (Team 2016). Data analysis was performed with linear model, 2 years, 2 hybrids, 4 replications. Algorithm of the replication model:

model= aov(content values ~ EV*Hybrid), data= data)

Table 2

Amount of monthly rainfall (mm) during the growing season (Debrecen, 2020-2021)

Growing season	**Climate Avg. (1991-2020)**	**2020** monthly amount	**2021** monthly amount
Apr	45.5	16.5	33.3
May	59.3	45.0	66.1
June	66.8	118.5	6.4
July	67.7	148.5	70.2
Aug	46.4	70.0	38.2
Sept	47.3	47.0	18.6

Avg = average

Level of significance: 5 %. A multiple mean comparison test was not necessary because there were only two levels of the two treatments. Significant effects are marked with an asterisk. The values of each parameter tested, indicated by different letters (a, b, c, d), are significantly different.

Graphs were created using MS Excel 2019.

RESULTS AND DISCUSSION

Evaluation of heat stress effects in the adverse crop year

In 2021, the temperature anomaly in June was +3.0 °C, and the last third of the month was exceptionally warm, 6.4 °C warmer than average. The number of hot days (max. ≥ 30 °C) is 10, with temperatures reaching 35 °C on three occasions and 36.6 °C on the 24th. On only three days did 1-3 mm of precipitation occur, evaporating immediately.

The stress caused by the lack of water and the high temperatures had a negative effect on the assimilation of the plants and on the mass gain of stands. July was characterised by very hot weather with maximum temperatures exceeding 30 °C on 19 days. The highest temperature was the same as the maximum recorded in June (36.6 °C). There was an exceptional period of drought until the middle of the month (Fig. 1).

The hot weather continued in the first half of August, when maximum temperatures often reached 30 °C (9 hot days). There was no amount of rainfall that would have contributed significantly to the water supply of the crops during the harvest period, which is of great importance for yield.

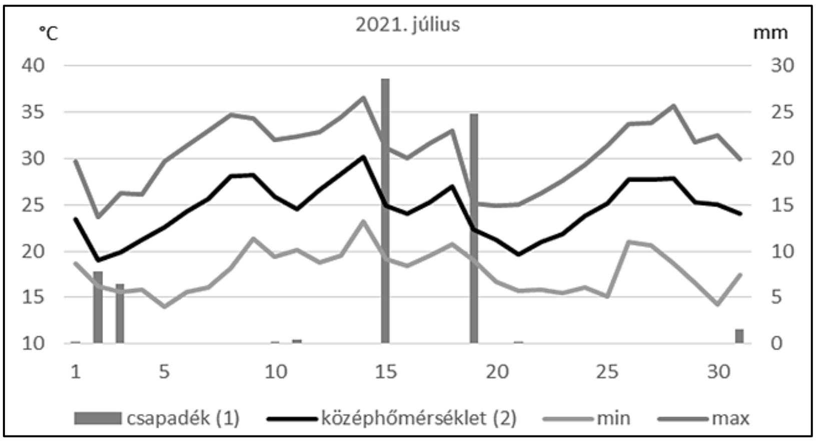

Fig. 1. Daily minimum, maximum and mean temperature and precipitation in July 2021 (University of Debrecen agricultural campus)

Yield, plant and ear height

Heat stress significantly reduces the yield of sweet maize hybrids. In the performed examinations, the harvested yield in unfavourable years was 26 % less in hybrid H1 and 24 % less in hybrid H2. It was shown that the effect of heat stress is greater than that of the difference between the examined sweet maize genotypes. By comparing the results of the two sweet maize hybrids, it was found that, in 2020, a favourable year, the hybrid H2 had 16 % more harvested yield, 20 % more wet ear weight and 19 % more grain weight (9.981 t/ha) than hybrid H1, and in 2021, an unfavourable year, H2 had 19 % more harvested yield, 19 % more wet ear weight and 18 % more grain weight (6.785 t/ha) than H1 (Fig. 2).

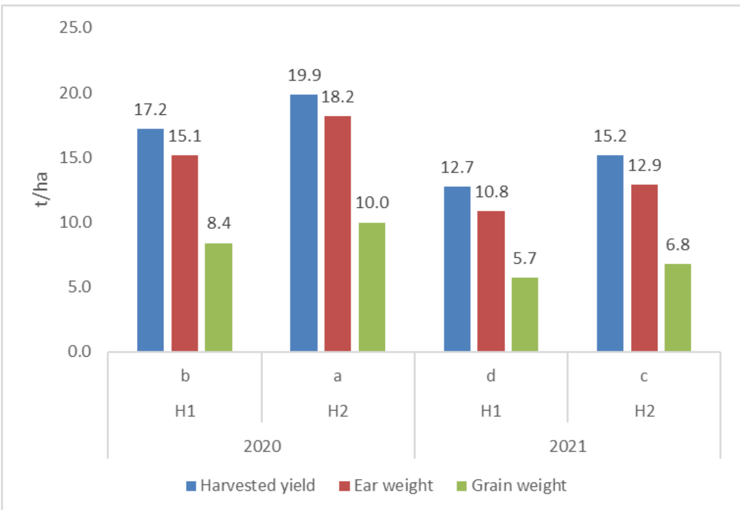

Fig. 2. Sweet maize hybrids' harvested yield, ear weight, grain weight t/ha (Debrecen, 2020-2021)

The obtained research results demonstrate a significant effect of crop year, especially of heat stress. Some researchers, in their experiment, show that yields of sweet corn hybrids measured at harvest differed only slightly in a given crop year. Consistent with the results of Sridic et al., 2016, it was demonstrated that genotype and year effects and their interactions influence the yield of sweet maize hybrids. Genetic endowments and morphological traits also determine maize yield according to Zhao et al., 2019. The obtained research results confirm the findings of Nemeskéri et al., 2019 and Mand et al., 2010, i.e. genetic background, environmental conditions, and heat stress effects combine to influence not only the quantity of harvested yield but also its quality (Fig. 3).

Fig. 3. Plant and ear height of sweet maize hybrids (Debrecen, 2020-2021)

Mineral content

Both examined sweet maize hybrids showed significant reduction in mineral element content under heat stress. It is a new finding that stress effect is best shown by the Mg content for each genotype, with the hybrid H1 showing a 16 % reduction and H2 a 22 % reduction in Mg content, under heat stress (Table 3).

Also, in agreement with the examination results, Cheach et al., 2019, found that Zn content of sweet maize is related to yield. The performed analyses demonstrated that Zn content differed steadily between the two hybrids, with not only yield (19 %), but also Zn content being significantly lower (8-10 %) under stress. Prashanti et al., 2017, measured different phosphorus, potassium, magnesium contents in sweet maize hybrids similar to the results obtained in this research.

Table 3

Mineral content of sweet maize hybrids (Debrecen, 2020-2021)

Year	Hybrid	Potassium	Phosphorus	Magnesium	Calcium	Iron	Zinc
		mg/kg					
2020	H1	10140 ± 184[c]	3534 ± 81[c]	1199 ± 22[b]	342 ± 8.2[c]	24 ± 0.4[b]	20 ± 0.45[c]
	H2	13970 ± 241[a]	4450 ± 99[a]	1526 ±2 5[a]	381 ± 8.5[a]	26 ± 0.41[a]	27 ± 0.26[a]
2021	H1	10063 ± 144[c]	3416 ± 72[c]	1011 ± 22[c]	285 ± 1.6[d]	21 ± 0.59[c]	18 ± 0.66[d]
	H2	11500 ± 226[b]	3700 ± 99[b]	1200 ± 21[b]	365 ± 8.2[b]	20 ± 0.59[d]	25 ± 0.48[b]
Hybrid		***	***	***	***	.	***
Year		***	***	***	***	***	***
Hybrid*Year		***	***	***	***	***	

Significance codes: '***' 0.001 '. ' 0.1 ' ' 1

In their experiments, Ray et al., 2019, found that the specific element content of sweet maize hybrids was also significantly influenced by the given crop year. Aineura et al., 2020, measured different amounts of Fe, similar to the performed analyses of this research. In addition, in these experiments, the Fe content of the two hybrids differed only slightly, but decreased significantly in both hybrids under heat stress.

Sweet maize sugar content

Based on the performed analyses, the two hybrids showed a different reduction in sugar content under heat stress. It was a significant result that the fructose content of the hybrid H2 decreased by 30 % and the glucose and sucrose content by 9-9 %, whereas the glucose content of the hybrid H1 decreased by 16 % and the fructose and sucrose content decreased by 12-12 %. In 2020, a favourable crop year, the hybrid H2 had 9 % higher fructose content, 31 % more glucose and 7 % more sucrose than hybrid H1. In 2021, an unfavourable crop year, hybrid H2 had lower fructose content, but 42 % more glucose and 11 % more sucrose than hybrid H1 (Table 4).

Table 4

Fructose, glucose, sucrose content of sweet maize hybrids (Debrecen, 2020-2021)

Year	Hybrid	Fructose	Glucose	Sucrose
		g/100g		
2020	H1	1.125 ± 0.05[ab]	0.62 ± 0.14[bc]	9.32 ± 0.36[b]
	H2	1.22 ± 0.01[a]	0.81 ± 0.03[a]	9.98 ± 0.11[a]
2021	H1	0.995 ± 0.02[b]	0.52 ± 0.09[c]	8.22 ± 0.14[c]
	H2	0.85 ± 0.17[c]	0.74 ± 0.16[ab]	9.13 ± 0.21[b]
Hybrid			**	***
Year		***		***
Hybrid*Year		*		.

Significance codes: '***' 0.001 '**'0.01 '*' 0.05 ' . ' ' 0.1 ' ' 1

In accordance with the findings of Abadi and Sugiharto, 2019, the research results presented in this paper demonstrated that the sugar content of sweet maize varies significantly between hybrids. According to Xie et al., 2016, the sugar content of sweet maize is impaired at higher temperatures. In line with this finding, it was demonstrated that sweet maize loses significant amounts of sugar content under heat stress. Similar to Feng et al., 2020, it was found that sweet maize sugar content is significant but it is greatly reduced under stress.

Sweet maize carotenoid content

The obtained results show a significant decrease in lutein content under heat stress, by 7 % in hybrid H2 and by 22 % in hybrid H1. A similar correlation was found for zeaxanthin, with a 14 % reduction in hybrid H2 and 25 % in hybrid H1. In the favourable crop year of 2020, in the sweet maize hybrid H2, lutein content was 12 %, zeaxanthin 59 %, B cryptoxanthin 128 %, and b carotene 42 % higher than in hybrid H1. In 2021, under unfavourable conditions, significantly different values were measured between the two examined genotypes, with the hybrid H2 containing 34 % more lutein, 83 % more zeaxanthin, 13 % more b cryptoxanthin and 33 % more beta carotene than H1 (Table 5).

Table 5

Lutein, zeaxanthin, B-crypthoxanthin, B -carotene content of sweet maize hybrids (2020-2021)

Year	Hybrid	Lutein	Zeaxanthin	B-crypthoxanthin	B-carot
		mg/kg			
2020	H1	8.54 ± 0.19^{c}	6.01 ± 0.01^{c}	0.32 ± 0.006^{b}	0.38 ± 0.013^{b}
	H2	9.57 ± 0.19^{a}	9.58 ± 0.16^{a}	0.73 ± 0.006^{a}	0.54 ± 0.001^{a}
2021	H1	6.65 ± 0.14^{d}	4.52 ± 0.14^{d}	0.16 ± 0.005^{d}	0.12 ± 0.004^{d}
	H2	8.92 ± 0.2^{d}	8.26 ± 0.03^{b}	0.18 ± 0.005^{c}	0.16 ± 0.001^{c}
Hybrid		***	***	***	***
Year		***	***	***	***
Hybrid*Year		***		***	***

Signif codes: '***' 0.001 ' ' 1

Calvo-Brenes and O'Hare, 2020, have shown rapid variability of carotenoids in sweet maize in their studies, consistent with the obtained findings of this research. Song et al., 2016, also reported that lutein, zeaxanthin and beta-cryptoxanthin are present in the highest amounts in sweet maize. Similar to the research of Song et al., 2018, a strong correlation was shown between the zeaxanthin and lutein content of sweet maize hybrids. The obtained research results are in agreement with those of Moongram et al., 2020, who demonstrated that lutein, a valuable compound, is present in high amounts in some sweet maize hybrids. It is a novel result that the decrease in zeaxanthin amount under heat stress was proportional to the decrease in lutein amount. It was also demonstrated that the relationship is hybrid-specific.

CONCLUSIONS

Based on the results of this experiment, to determine the yield and quality values of sweet maize hybrids, in addition to the genotype, the effects of heat stress in a given crop year should also be taken into account.

The average precipitation of the two examined years did not differ significantly, the major difference was found in the number of days with heat stress. In 2021, the average temperature was higher, which resulted in lower yields, reduced nutrient content and poorer quality. The effect of heat stress differs in each phenophase. The extra heat stress in the vegetative phase causes leaf senescence, and it brings forward flowering in the generative phase.

The obtained research results show that heat stress during the grain filling period has a direct detrimental effect on both yield and the quality of sweet maize.

The mineral content is significantly reduced under heat stress, with the change in Mg content demonstrating the stress effect the most significantly. A strong correlation was measured between the yield and Zn content of sweet maize under heat stress.

Under heat stress, sweet maize hybrids lost sugar content, with the rate of sugar loss varying between genotypes.

Under heat stress, the examined sweet maize hybrids lost carotenoid content to various extents. The decrease in lutein and zeaxanthin was similar in the heat stress period. Overall, it was found that the sugar, carotenoid and mineral element content of sweet maize hybrids decreased under heat stress. Heat damage can be mitigated by professional precision management, but the effects of heat stress cannot be completely prevented.

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