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# Sweet Corn Yield and Sugar Content Depending on Genotype, Sowing Date and Irrigation

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**ABSTRACT**

The research examines the influence of year, sowing date, sweet corn genotype (*Zea mays* L. *saccharata* Sturt.), and irrigation norm on productive traits and sugar content in sweet corn kernels. The experiment was set up in a completely randomized block design with four replications. In both years, sowing was done in two periods: end of April - beginning of May and mid-July. Three hybrids (Enterprise, Union, and Sweet Nugget) were observed under three irrigation treatments: full norm (100%), reduced norm (50%) and natural wetting (control). Combined analysis of variance (pooled ANOVA) showed a statistically significant effect on all examined yield and sugar content parameters, as well as their higher-order interactions.

Hybrid Enterprise stood out as the most productive, with the highest values of ear weight, kernel weight (up to 272.13 g) and kernel yield (up to 16.25 t $ha^{-1}$ in the first year and up to 13.66 t ha-1 in the second year), especially in the second sowing date with full or reduced irrigation norm, with a shelling percentage over 70%. The highest content of total sugars (39.71% in the first year and 40.39% in the second year) was achieved in the Sweet Nugget hybrid in the first sowing date under natural moisture conditions, where a slight water deficit stimulates sugar concentration. The obtained results highlight the advantages of the Enterprise hybrid for high yield under irrigation conditions and the Sweet Nugget hybrid for kernel quality (sweetness), and underscore the importance of factor interactions.

## 1. INTRODUCTION

Sweet corn (*Zea mays* L. *saccharata* Sturt.) is a vegetable crop of exceptional nutritional value, rich in starch, sugars, proteins and carotenoids such as zeaxanthin and lutein, which ranks it among species with significant economic and health potential (Janošević et al., 2017; Srdić et al., 2019; Dragičević et al., 2021). Its soft, juicy, and sweet kernel at milk maturity is suitable for direct consumption in the fresh state and for industrial processing (Rattin et al., 2018; Gavrić and Omerbegović, 2020). In modern agriculture, achieving high yields and optimal kernel quality depends on the precise coordination of agroecological factors, the genetic basis of hybrids, and agrotechnical measures, with special attention paid to sowing date and irrigation norm.

Optimum sowing date enables more efficient use of available moisture and favorable temperature conditions, which directly affects the processes of photosynthesis, plant growth and kernel formation (Kara, 2011; Rahmani et al., 2016; Biberdžić et al., 2018a; Banotra et al., 2021; Kılınç et al., 2023; Stojiljković et al., 2025a). A delay in sowing, even by 10–15 days, can reduce yield by 12–15% (Shibzukhov et al., 2021), while late sowing without irrigation significantly limits the productive traits of all maize hybrids (Rajičić et al., 2025). Sowing date, genotype selection and their mutual interaction are the most significant factors in determining yield and quality (Ugur and Maden, 2015; Do Franco et al., 2016; Biberdžić et al., 2018b).

The genetic variability of sweet corn hybrids decisively influences phenotypic characteristics, such as ear weight and sugar content, which are conditioned by the specifics of the production environment (Ganesan et al., 2017; Subaedah et al., 2021; Šević et al., 2025). Previous researches confirms that genotypic diversity significantly modulates ear parameters and kernel sugar concentration (Srdić et al., 2016; Subaedah et al., 2021), with sucrose as the dominant sugar responsible for sweetness and overall use value (Kara et al., 2012; Metha et al., 2017). In addition to increasing kernel yield (Rajičić et al., 2024), one of the main goals of plant breeders is to improve nutritional quality, especially given the growing demand for plant proteins, the popularity of organic and vegan diets, and health considerations (Urošević et al., 2023).

In conditions of climate change, characterized by irregular distribution of precipitation and extreme temperatures (Terzić et al., 2025), the irrigation norm becomes indispensable for the stability of production (Ertek and Kara, 2013). Water deficit significantly reduces kernel yield and quality, especially ear weight and sugar content (Afšar et al., 2014; Badr et al., 2021). The full norm of irrigation ensures the highest yield, while any reduction in the rate directly reduces the measured (Ertek and Kara, 2013). Drip-by-drop systems enable precise supply of water and nutrients (Oktem et al., 2003), and reduced norms (e.g., 50% of full evapotranspiration) can contribute to economic production and increase the sugar content in the kernel (Dicket and Tracy, 2001; Tupajić et al., 2024a; Burhan et al., 2016).

The goal of the research was to determine the influence of irrigation norm and sowing date on yield components and kernel sugar content across different sweet corn hybrids, with a special focus on interactions among genotype, year, sowing date, and irrigation. The novelty of the work lies in the integrated approach, which, through joint analysis of variance, includes a four-way interaction (year × sowing date × hybrid × irrigation norm) under specific agroecological conditions in Serbia, providing practical recommendations for adapting production to limited water resources and climate change.

## 2. MATERIALS AND METHODS

The experiment was conducted during two growing seasons, 2022 and 2023 in the area of the village of Bresje, municipality of Velika Plana, Podunavski district (Serbia). Soil characteristics and climatic conditions of the experimental area are described in detail because they are of exceptional importance for evaluating data from experiments with irrigation and different sowing dates. Standard agrotechnical measures were applied in sweet corn cultivation, with a crop density of about 65.000 plants per hectare (spacing of 70 × 22 cm). The trial was set up according to a randomized block design with four replications. Four factors were observed in the research: year (first year: 2022; second year: 2023), sowing date (first sowing date: the end of April to the beginning of May, second sowing date: mid-July), hybrid (Enterprise, Union, Sweet Nugget) and irrigation norm (control: natural moistening without any additional irrigation, reduced norm (50%): half the amount of the full irrigation norm, full norm (100%).

Soil characteristics

The soil in the experimental area is prone to occasional overwetting, with pronounced variations in profile depth. In the surface layer (0–10 cm), it is a loose, clay-loam type, weakly carbonated, without signs of excessive wetting or anthropogenic influence. In the 10–35 cm layer, glial processes were observed, likely due to long-term, intensive wetting from previous cultures (blueberry under agrotextile with abundant irrigation and fertilization). The color is bluish-green; the texture is clayey, compact, without structure, and carbonate, with brick fragments and undecomposed maise remains at a depth of 15–20 cm, indicating anaerobic conditions, high acidity, or nitrogen deficit. The 35–65 cm layer shows

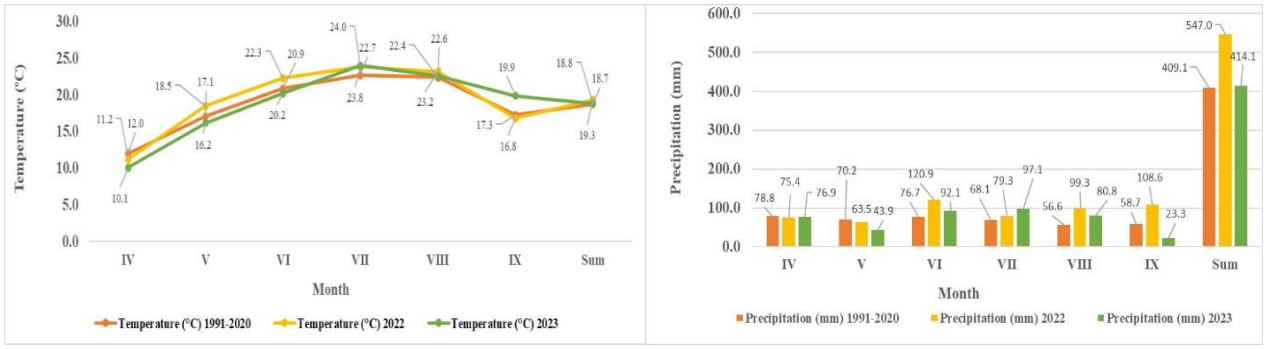
reddening processes, a clay-clay texture, a light brown color, less compaction, the absence of carbonates, and traces of the root system. At a depth of 65–100 cm, the soil is yellowish-brown, loamy to clayey-loamy, less compacted and without carbonates.

Agrochemical analyses conducted before sowing at the Laboratory for Agrochemical Analysis of Soil at the Agricultural Advisory and Expert Service of Smederevo confirmed the soil's acidic reaction, anaerobic conditions, low available nitrogen content, and the absence of carbonates in most layers. pH was measured by the Köppen method in KCl, humus by the Kocman method, total nitrogen by calculation from the humus, and easily accessible phosphorus ($P_2O_5$) and potassium ($K_2O$) by the Enger-Rimm AL method. The surface layer (0–10 cm) has a slightly acidic reaction (pH 5.5), a low carbonate content (<1%) and a low organic matter content (2%). The 10–35 cm layer was acidic (pH 4.5), with low humus content (2.10%) and nitrogen content (0.06%). The deeper layers (35–100 cm) showed an acidic reaction (pH 5.0), a very low humus content (1.5%), and a medium to good supply of phosphorus and potassium ($P_2O_5$ 10–20 mg/100 g and $K_2O$ 10–25 mg/100 g) of the soil.

In order to correct soil fertility, before sowing in the fall of 2021, calcification with 2 t $ha^{-1}$ CaO (finely ground calcium carbonate) was performed, by plowing to a depth of 20–30 cm, which raised the pH to about 6.5 and reduced the toxicity of Al and Mn. 30 t $ha^{-1}$ of composted cow manure was added to improve soil structure and organic matter. Basic fertilisation included 400 kg $ha^{-1}$ NPK (8:26:26), ploughed at 20–25 cm. Fertilizations was done in two phases: 50 kg $ha^{-1}$ N (as lime ammonium nitrate 27%N) at the 4-leaf stage and another 50 kg $ha^{-1}$ N (as lime ammonium nitrate 27%N) before threshing. Weed control was performed mechanically (intermediate cultivation) and manually at the 4–6 leaf stage, with 2–3 interventions per season, without herbicides to preserve the experiment's ecological character.

Meteorological characteristics of the investigated area

Meteorological conditions during the growing season of sweet corn in the two-year survey (2022–2023) compared to the multi-year average (1991–2020) are shown in Figure 1a and 1b. The data show that the years 2022 and 2023 were significantly warmer than the long-term average. The trend in average monthly temperatures shows an increase from April to July, with a maximum in July. The research years are characterized by higher average temperatures in almost all months of the growing season. The first year (2022) was extremely warm in the spring and early summer months (May 18.5 °C, June 22.3 °C), while the second year (2023) had extremely warm periods during the late summer and autumn months. April 2023 is the only month with a lower average temperature (10.1 °C) than the average (11.2 °C).




(a) (b)

Figure 1. Average monthly air temperatures (a) and the distribution of precipitation (b) during the experimental periods of 2022 and 2023 and multi-year averages (1991-2020) in the Bresje location

Precipitation variation

May precipitation was lower than average (76.9 mm) in 2022 (70.2 mm) and 2023 (43.9 mm). June: 120.9mm (2022), 92.1mm (2023) vs 76.7mm average. July: 97.1 mm (2022), 79.3 mm (2023) vs. 68.1 mm. September: 108.6 mm (2022), 23.3 mm (2023) vs. 48.4 mm. Cumulative: 547.0mm (2022), 414.1mm (2023) vs 409.1 mm average. These variations affected the natural wetting regime and the need for irrigation.

Determination of irrigation norm

The water-physical properties of the soil were determined from samples in disturbed and undisturbed conditions (Kopec cylinders) analyzed in the soil reclamation laboratory of the Faculty of Agriculture, University of Belgrade. The tensiometric curve, derived from the ratio of humidity to water potential, was used to precisely define the field water capacity (PVK) and the wilting point to adjust irrigation.

In both years of the research, irrigation was carried out with a drip-by-drip system with strips with a capacity of 10 l•m-1•h, placed between the rows. Tested norms: Control: natural moistening without additional irrigation (the total amount of water from precipitation varied by year and month); Reduced norm (50%): half the amount compared to the full norm; Full norm (100%). Humidity was monitored by tensiometers at a depth of 0.3 m, placed in the full norm variant, maintaining 60% PVK. Control was performed every 3-4 days, and the watering rate was calculated according to the formula: $Nz = 10 \cdot D \cdot (PVK\% \text{ vol} - \theta z) = mm \cdot m$ -2; Where Nz is the watering norm (mm $m^{-2}$), D is the depth of the soil layer (m), PVK% vol field capacity in volume percentage, and θz is the measured humidity. The duration of watering is determined according to the rate and flow of the strip, with buffer zones between treatments to avoid lateral infiltration.

Based on actual rainfall and control frequency (every 3–4 days), the total amounts of water per treatment for the growing season (from sowing to harvest) were:

First sowing date (end of April/beginning of May - July): 2022 (rainfall 305 mm): control 305 mm; 50% of the norm 361.5 mm; 100% of the norm 418 mm. 2023 (rainfall 235 mm): control 235 mm; 50% of the norm 328 mm; 100% of the norm 421 mm.

Second sowing date (mid-July - September): 2022 (rainfall 242 mm): control 242 mm; 50% of the 305 mm norm; 100% of the norm 368 mm. 2023 (precipitation 179 mm): control 179 mm; 50% of the norm of 326 mm; 100% of the norm 410 mm.

Plant material

During the two-year research, the following sweet corn hybrids were monitored: Enterprise $F_1$ – hybrid of standard sweetness with a vegetation period of about 85 days, tall plants and a solid stem; Union $F_1$ – triple hybrid of standard quality, with a long ear, 90-day vegetation period and lush growth; Sweet Nugget $F_1$ – the earliest super sweet hybrid, with a ripening period of 65–68 days, a medium bushy plant and a firm stem. Irrigation and natural humidification were applied to all hybrids.

Sowing and harvest dates

In both years of the study, the experiment was conducted over two sowing dates. The first sowing dates were on April 30, 2022, and May 3, 2023, adjusted to optimal germination temperature conditions (minimum 10–12 °C in the soil), 10–15 days after mercantile maize sowing to avoid late frosts. The second sowing date was carried out on July 10, 2022, and July 13, 2023, after the wheat harvest, to test later production. Ears were harvested 22–25 days after fertilization (stage of milky grain maturity, when the sugar content reaches a maximum and the moisture content of the kernel is 70–75%). Harvest date was determined by visual assessment and kernel dry matter measurement: harvest began when 50–70% of plants had reached milk maturity. Harvest dates in the first sowing date: 20–25. July 2022 and 25–30 July 2023. In the second sowing date: 5–12. September 2022 and 7–15 September 2023, depending on the hybrid and irrigation norm. The same arrangement of hybrids and treatments was applied in both sowing dates. Land preparation for the first sowing date included autumn ploughing and pre-sowing preparation, while for the second sowing date, it included ploughing immediately after the wheat harvest. During the research, regular agrotechnical measures were applied. Special attention was paid to monitoring the maize borer (*Ostrinia nubilalis*). Parameters analyzed included ear and kernel weight, shelling percentage and kernel yield.

Chemical analyses

Frozen samples of fresh kernel were analyzed in the laboratory for applied chemistry and food technology of the Faculty of Agriculture in Čačak. The content of total sugars, reducing sugars, invert sugars and sucrose was determined volumetrically, using the Luff-Schoorl method. The Luff-Schoorl method involves reduction of copper sulfate ($CuSO_4$) from Luff's solution to copper(I)-oxide ($Cu_2O$) in the presence of reducing sugars (natural invert). This method measures the unreduced $Cu^{2+}$ ions iodometrically. Additionally, non-reducing sugars are converted to reducing sugars through acid hydrolysis, enabling the calculation of total sugar content. The content of invert sugar is calculated from the difference between the content after inversion and before inversion, and the content of sucrose is calculated by multiplying the content of invert sugar by a factor of 0.95 (Schneider F., 1979; AOAC, 1995; Nikolić et al., 2023).

Statistical data analysis

The IBM SPSS Statistics software, version 26.0, was used for the statistical analysis of the obtained data. An Analysis of Variance (ANOVA) was applied to assess the influence of sowing date, hybrid and irrigation norm, with significance levels set at $p<0.05$. Tukey's HSD (Honestly Significant Difference) post-hoc test was used to perform multiple pairwise comparisons between all group means at statistical significance level 0.05. It was determined which specific groups had statistically significant differences by comparing the difference between each pair of means with a calculated critical value (HSD). A compact representation is given with different letters denoting significant differences. Minitab Statistical Software (Trial version) used for Heatmap was conducted to determine the relationship between the studied traits of sweet corn hybrids. The results are presented tabularly and graphically, enabling the visualization of the influence of factors on the examined properties.

## 3. RESULTS

The results of the variance analysis of the two-year study, shown in Table 1, indicate that the factors observed individually (sowing date, hybrid, and irrigation) had a statistically significant effect on all traits. In contrast, the factor year had a statistically significant effect on kernel weight and total kernel yield. However, the interaction of high-order factors (year × sowing date × hybrid × irrigation) showed a statistically significant difference in the average values obtained for all traits.

Table 1. Analysis of variance (ANOVA) and the significance of the influence of factors on the productive properties of sweet corn

| | **Total ear weight** | **Kernel weight** | **Total kernel yield** | **Shelling percentage** |
|---|---|---|---|---|
| **EFFECT** | F test | F test | F test | F test |
| **Year** | 1.51ns | 10.56** | 36.53** | 1.51ns |
| **Sowing date** | 87.52** | 41.90** | 295.19** | 87.52** |
| Sowing date x Year | 4.31* | 24.35** | 63.29** | 4.31* |
| **Hybrid** | 88.12** | 292.49** | 1059.77** | 88.12** |
| Hybrid x Year | 4.85** | 2.73ns | 6.35** | 4.85** |
| Hybrid x Sowing date | 4.23* | 1.91ns | 8.24** | 4.23* |
| Hybrid x Sowing date x Year | 43.17** | 45.75** | 139.91** | 43.17** |
| **Irrigation** | 40.08** | 143.24** | 667.16** | 40.08** |
| Irrigation x Year | 6.50** | 14.81** | 34.76** | 6.50** |
| Irrigation x Sowing date | 0.41ns | 8.76** | 25.06** | 0.41ns |
| Irrigation x Hybrid | 3.65** | 13.54** | 72.54** | 3.65** |
| Irrigation x Year x Sowing date | 5.77** | 4.69** | 22.82** | 5.77** |
| Irrigation x Year x Hybrid | 2.44* | 1.76ns | 5.97** | 2.44* |
| Irrigation x Sowing date x Hybrid | 2.80* | 2.97* | 9.18** | 2.80* |
| Year x Sowing date x Hybrid x Irrigation | 4.55** | 4.07** | 12.17** | 4.55** |

** Highly significant at $p < 0.01$ probability level; * Significant at $p < 0.05$ probability level; ns-Not significant at $p > 0.05$ level; Sig.-significant; F-test – F statistics value calculated.

The influence of irrigation norms at different sowing dates on yield and yield components of three sweet corn hybrids in the first year of research is shown in Table 2a. It is clear that the irrigation norm has a decisive influence on all measured parameters, but efficiency depends on the genotype. The Enterprise hybrid proved to be the most productive in all conditions. In the second sowing date, with full irrigation (IR 100%), it achieved the maximum kernel weight of 272.13 g and the highest yield of 16.25 t $ha^{-1}$. This hybrid makes the best use of the available water, as confirmed by the increase in its average yield from 9.92 to 13.96 t $ha^{-1}$ in the comparison of sowing dates. This suggests that the meteorological conditions during the second date growth cycle were better aligned with the critical stages of plant development (flowering and kernel filling). The increased irrigation norm in the first sowing date could not fully compensate for a limiting factor (probably heat stress or an unfavorable rainfall distribution). In contrast, in the second sowing date, the irrigation norm fully manifested its effect in synergy with external factors. Hybrid Union shows stability with yields reaching up to 13.06 t $ha^{-1}$.

On the other hand, the hybrid Sweet Nugget achieved the weakest results in the research. Its yield ranged from 6.16 to 9.06 t $ha^{-1}$ and showed a lower response to increased irrigation than the other two hybrids. The general trend shows a linear increase in parameter values from the control treatment to higher irrigation norms. Irrigation directly affects kernel weight, with the Enterprise hybrid almost doubling kernel weight compared to the control. The average shelling percentage values are more stable. However, it shows a tendency to increase at higher irrigation norms, reaching values over 70% in the Enterprise hybrid during the second sowing date. This suggests that the conditions at later sowing had a greater influence on kernel development than on the ear, which is crucial for final economic profitability. In the case of the Sweet Nugget hybrid, the value of the average yield is similar in different sowing dates (7.80 and 7.94 t $ha^{-1}$), which indicates that this hybrid is genetically limited and that under better conditions (later sowing or higher irrigation norm), it does not have a greater impact on exceeding a specific productivity limit.

Table 2a. Average values of sweet corn hybrid yield components in two sowing dates for first year research period (2022).

| | **I – SD** | **II – SD** |
|---|---|---|

| H | I | TEW (g) | KW (g) | TKY (t ha$^{-1}$) | SP (%) | TEW (g) | KW (g) | TKY (t ha$^{-1}$) | SP (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Control | 213.37$^{hijklm}$ | 122.77$^{lmnop}$ | 6.80$^{klmn}$ | 55.99$^{hij}$ | 240.63$^{ghij}$ | 162.17$^{ghijkl}$ | 9.72$^{efgh}$ | 65.78$^{abcde}$ |
| **E** | IR 50% | 305.97$^{cde}$ | 187.97$^{defgh}$ | 11.07$^{de}$ | 60.49$^{efghi}$ | 373.93$^{ab}$ | 263.87$^{ab}$ | 15.92$^{a}$ | 70.44$^{a}$ |
| $F_1$ | IR 100% | 318.87$^{c}$ | 207.37$^{cdef}$ | 11.89$^{cd}$ | 63.81$^{abcdefg}$ | 392.47$^{a}$ | 272.13$^{a}$ | 16.25$^{a}$ | 69.20$^{ab}$ |
| | **Average** | **279.40** | **172.70** | **9.92** | **60.10** | **335.68** | **232.72** | **13.96** | **68.47** |
| | Control | 234.97$^{hijk}$ | 144.33$^{hijklmn}$ | 8.70$^{ghij}$ | 60.86$^{defghi}$ | 194.47$^{jklm}$ | 130.37$^{klmnop}$ | 7.95$^{ijkl}$ | 65.62$^{abcdef}$ |
| **U** | IR 50% | 250.73$^{fghi}$ | 147.17$^{cde}$ | 9.01$^{ghij}$ | 58.70ghi | 325.67$^{bc}$ | 218.13$^{cde}$ | 13.06$^{bc}$ | 66.53$^{abcde}$ |
| $F_1$ | IR 100% | 291.93$^{cdefg}$ | 180.93$^{bdc}$ | 10.97$^{de}$ | 62.11$^{cdefgh}$ | 326.27$^{bc}$ | 221.13bcd | 12.99$^{bc}$ | 68.17$^{abc}$ |
| | **Average** | **259.21** | **157.48** | **9.56** | **60.56** | **282.13** | **189.94** | **11.33** | **66.77** |
| **SN** | Control | 171.00$^{m}$ | 101.60$^{nop}$ | 6.16$^{n}$ | 57.91$^{ghij}$ | 171.00$^{m}$ | 101.60$^{nop}$ | 6.30$^{mn}$ | 57.91$^{ghij}$ |
| $F_1$ | IR 50% | 237.73$^{ghijk}$ | 145.37$^{hijklmn}$ | 8.69$^{ghij}$ | 60.71$^{defghi}$ | 243.50$^{fghij}$ | 149.90$^{hijklmn}$ | 9.06$^{fghi}$ | 60.80$^{defghi}$ |
| | IR 100% | 240.63$^{ghij}$ | 145.40$^{ijklmno}$ | 8.55$^{ghij}$ | 60.20$^{efghi}$ | 237.00$^{ghijk}$ | 140.87$^{hijklmn}$ | 8.47$^{hij}$ | 58.99$^{fghi}$ |
| | **Average** | **216.46** | **130.79** | **7.80** | **59.60** | **217.17** | **169.07** | **7.94** | **59.23** |

H- Hybrid: E-Enterprise $F_1$, U-Union $F_1$, SN-Sweet Nugget $F_1$; I - Irrigation: Control– treatment without irrigation, IR – 50% - treatment reduced norm irrigation, IR -100% - treatment full irrigation norm. SD – Sowing date: I - end of April/beginning of May – July; II - mid-July. TEW- total ear weight; KW – kernel weight; TKY – total kernel yield; SP- shelling percentage. Tukey's test (different letters indicate significant differences).

On the first date of sowing, specific abiotic stresses are more pronounced in plants, which limit the height of the yield regardless of the available amount of water. To achieve maximum yields, preference is given to the combination of Enterprise herbicide and full irrigation at the second sowing date, which showed higher production potential, suggesting that meteorological conditions are more favorable than at the first sowing date.

The data in Table 2b show that in the second year of the research, in all combinations of new growth norms and sowing dates, the Enterprise hybrid achieves the best results with a maximum yield of 13.66 t ha$^{-1}$. With reduced irrigation at the first sowing date, the Sweet Nugget hybrid recorded the lowest values, particularly for kernel weight and total kernel yield. Reduced irrigation norms yield results comparable to those at the full norm, suggesting high water-use efficiency in these sweet corn hybrids.

Table 2b. Average values of sweet corn hybrid yield components (g) in two sowing dates for second year research period (2023).

| | | I - SD | | | | II - SD | | | |
|---|---|---|---|---|---|---|---|---|---|
| H | I | TEW (g) | KW (g) | TKY (t ha$^{-1}$) | SP (%) | TEW (g) | KW (g) | TKY (t ha$^{-1}$) | SP (%) |
| | Control | 297.90$^{cdef}$ | 198.63$^{cdefg}$ | 9.96$^{efg}$ | 66.37$^{abcde}$ | 219.37$^{hijklm}$ | 130.83$^{klmnop}$ | 8.11$^{ijk}$ | 58.04$^{ghij}$ |
| **E** | IR 50% | 337.30$^{bc}$ | 237.30$^{abc}$ | 13.66b | 70.04$^{ab}$ | 312.70$^{cd}$ | 220.43$^{bcde}$ | 13.40$^{b}$ | 69.37ab |
| $F_1$ | IR 100% | 325.83$^{bc}$ | 221.63$^{bcd}$ | 12.71$^{bc}$ | 67.36$^{abcd}$ | 298.03$^{cdef}$ | 201.60$^{cdefg}$ | 12.53$^{bc}$ | 67.47$^{abcd}$ |
| | **Average** | **320.34** | **219.19** | **12.11** | **67.92** | **276.70** | **184.29** | **11.35** | **64.96** |
| | Control | 227.93$^{hijkl}$ | 128.80$^{hijklm}$ | 7.84ijkl | 55.75$^{hij}$ | 222.40$^{hijklm}$ | 146.40$^{hijklm}$ | 8.86$^{ghij}$ | 63.34$^{bcdefg}$ |
| **U** | IR 50% | 259.77$^{defgh}$ | 176.30$^{efghij}$ | 10.59$^{de}$ | 66.71$^{abcde}$ | 251.07$^{efghi}$ | 169.47$^{fghijk}$ | 10.46$^{ef}$ | 66.02$^{abcde}$ |
| $F_1$ | IR 100% | 260.63$^{defgh}$ | 163.47$^{fghijkl}$ | 9.95$^{efg}$ | 62.36$^{cdefgh}$ | 290.47$^{cdefg}$ | 204.27$^{cdefg}$ | 12.87$^{klmn}$ | 70.03$^{ab}$ |
| | **Average** | **249.44** | **156.19** | **9.46** | **61.61** | **254.64** | **173.38** | **10.73** | **66.46** |
| | Control | 177.63$^{lm}$ | 93.60$^{p}$ | 5.68$^{n}$ | 51.73$^{j}$ | 203.53$^{ijklm}$ | 127.30$^{klmnop}$ | 7.60$^{hij}$ | 61.81$^{cdefgh}$ |
| **SN** | IR 50% | 182.87$^{klm}$ | 107.33$^{mnop}$ | 6.69$^{lmn}$ | 58.28$^{ghij}$ | 211.83$^{hijklm}$ | 132.27$^{jklmnop}$ | 8.05$^{ijkl}$ | 62.01$^{cdefgh}$ |
| $F_1$ | IR 100% | 173.00$^{lm}$ | 96.83$^{op}$ | 6.13$^{n}$ | 54.51$^{ij}$ | 205.83$^{hijklm}$ | 128.73$^{klmnop}$ | 7.87$^{ijkl}$ | 62.17$^{cdefgh}$ |
| | **Average** | **177.83** | **99.26** | **6.17** | **54.84** | **207.07** | **129.43** | **7.84** | **62.00** |

H- Hybrid: E-Enterprise $F_1$, U-Union $F_1$, SN-Sweet Nugget $F_1$; I - Irrigation: Control– treatment without irrigation, IR – 50% - treatment reduced norm irrigation, IR -100% - treatment full irrigation norm. SD – Sowing date: I - end of April/beginning of May – July; II - mid-July. TEW- total ear weight; KW – kernel weight; TKY – total kernel yield; SP- shelling percentage. Tukey's test (different letters indicate significant differences).

Also, there is a noticeable drop in the average parameter values of the Enterprise hybrid between sowing dates. In contrast, the Sweet Nugget hybrid shows a slight trend of growth or stability in the second sowing date. Statistical analysis indicates significant differences among treatments, confirming that yield variation is directly related to hybrid genetics and the applied irrigation norm, with the hybrid Enterprise standing out as the most productive.

Analysis of variance (Table 3) indicates a statistically significant effect of all factors, observed individually, on the quality of sweet corn kernels in terms of sugar content. Mutual interaction of all factors, i.e. high order (year x sowing date x hybrid x irrigation) showed only statistically significant differences in sucrose.

Table 3. Analysis of variance (ANOVA) and the significance of the influence of factors on the content of different types of sugar of kernel sweet corn

| | **Total sugars** | **Reducing sugars** | **Invert sugars** | **Sucrose** |
|---|---|---|---|---|
| **EFFECT** | F test | F test | F test | F test |
| **Year** | 19.70** | 15.70** | 640.47** | 1019.08** |
| **Sowing date** | 1139.91** | 70.27** | 147846.46** | 214171.96** |
| Sowing date x Year | 0.44ns | 0.120ns | 40.58** | 75.38** |
| **Hybrid** | 9478.70** | 2151.37** | 472333.53** | 676936.75** |
| Hybrid x Year | 0.02ns | 0.13ns | 14.18** | 19.72** |
| Hybrid x Sowing date | 96.35** | 1649.05** | 66839.36** | 97287.14** |
| Hybrid x Sowing date x Year | 0.00ns | 0.13ns | 11.43** | 19.94** |
| **Irrigation** | 849.78** | 416.75** | 30852.15** | 42162.27** |
| Irrigation x Year | 1.15ns | 1.22ns | 17.60** | 20.37** |
| Irrigation x Sowing date | 329.03** | 22.93** | 27110.80** | 38576.31** |
| Irrigation x Hybrid | 288.73** | 97.29** | 14841.06** | 20402.49** |
| Irrigation x Year x Sowing date | 0.05ns | 0.060ns | 7.67** | 9.08** |
| Irrigation x Year x Hybrid | 0.04ns | 0.073ns | 2.83* | 5.21** |
| Irrigation x Sowing date x Hybrid | 149.22** | 239.36** | 20810.56** | 30143.97** |
| Year x Sowing date x Hybrid x Irrigation | 0.10ns | 0.23ns | 1.81ns | 4.06** |

** Highly significant at $p < 0.01$ probability level; * Significant at $p < 0.05$ probability level; ns-Not significant at $p > 0.05$ level; Sig.-significant; F-test – F statistics value calculated.

Analysis of sugar content across different types of sugars in the investigated sweet corn hybrids revealed significant variations depending on irrigation norm, hybrid, and sowing date in the first year of the study (Table 4a). The hybrid had the greatest influence on the examined parameters, with Sweet Nugget standing out with statistically significantly higher total and other sugars than the Enterprise and Union hybrids. The highest average content of total sugars in the hybrid Sweet Nugget during the first sowing date was observed in the control treatment, at 39.71%, which is interesting because mild water stress often increases sugar concentration. In this case, the control treatment had more optimal conditions for accumulation (precipitation distribution during the growing season). Applying irrigation (IR at 50% and 100%) during that period leads to a drop in sugar concentration, likely due to "dilution" caused by a higher concentration of other substances in the kernel. During the second sowing date, the highest average value (37.29%) is observed at a reduced irrigation norm.

In contrast, the Union hybrid had the lowest average sugar content, particularly for sucrose, ranging from 2.90% to 6.79%. The content of sucrose and inverted sugars doubles during the second sowing date under irrigation, indicating that later sowing and favorable meteorological conditions in the first year of the study favor sugar synthesis. Statistical analysis confirms that the differences between the control and treated groups were most pronounced in the Sweet Nugget hybrid, which has a high genetic potential for sugar accumulation.

Table 4a. Average values of sweet corn hybrid on the content of different types of sugar in two sowing dates for first year research period (2022).

| | | I - SD | | | | II - SD | | | |
|---|---|---|---|---|---|---|---|---|---|
| H | I | TS (%) | RS (%) | IS (%) | Suc (%) | TS (%) | RS (%) | IS (%) | Suc (%) |
| E $F_1$ | Control | $12.57^{fghi}$ | $5.70^{fghi}$ | $6.88^{defgh}$ | $6.55^{defghi}$ | $15.39^{efg}$ | $9.88^{cde}$ | $5.55^{ghi}$ | $5.26^{efghij}$ |
| | IR 50% | $7.70^{mn}$ | $2.24^{j}$ | $5.51^{ghi}$ | $5.22^{efghij}$ | $12.92^{fgh}$ | $5.84^{fgh}$ | $8.09^{defg}$ | $7.67^{def}$ |
| | IR 100% | $8.97^{jklmn}$ | $3.04^{hij}$ | $5.89^{defghi}$ | $5.58d^{efghij}$ | $15.86^{ef}$ | $11.84^{abc}$ | $3.98^{hi}$ | $3.77^{hij}$ |
| | **Average** | **9.75** | **3.66** | **6.09** | **5.78** | **14.72** | **9.19** | **5.87** | **5.56** |
| U $F_1$ | Control | $10.45^{hijklm}$ | $6.97^{efg}$ | $3.09^{i}$ | $2.94^{j}$ | $11.25^{hijkl}$ | $3.00^{hij}$ | $8.27^{defg}$ | $7.85^{def}$ |
| | IR 50% | $7.03^{n}$ | $2.99^{hij}$ | $3.04^{i}$ | $2.91^{j}$ | $11.48^{hijk}$ | $3.49^{hij}$ | $7.84^{defg}$ | $7.44^{def}$ |
| | IR 100% | $6.97^{n}$ | $3.96^{ghij}$ | $2.99^{i}$ | $2.85^{j}$ | $7.67^{mn}$ | $2.22^{j}$ | $5.32^{ghi}$ | $5.07^{fghij}$ |
| | **Average** | **8.15** | **4.64** | **3.04** | **2.90** | **10.13** | **2.90** | **7.14** | **6.79** |
| SN $F_1$ | Control | $39.71^{ab}$ | $14.06^{ab}$ | $25.49^{c}$ | $24.21^{c}$ | $36.54^{b}$ | $10.81^{bcd}$ | $25.60^{c}$ | $24.30^{c}$ |
| | IR 50% | $20.68^{d}$ | $11.81^{abc}$ | $8.^{87def}$ | $8.43^{de}$ | $37.29^{ab}$ | $7.79^{def}$ | $29.57^{ab}$ | $28.10^{ab}$ |
| | IR 100% | $20.94^{d}$ | $14.22^{a}$ | $7.^{64defg}$ | $7.25^{dfg}$ | $27.27^{c}$ | $3.58^{hij}$ | $23.65^{c}$ | $22.85^{c}$ |
| | **Average** | **27.11** | **13.36** | **14.00** | **13.30** | **33.70** | **7.39** | **26.28** | **25.08** |

H- Hybrid: E-Enterprise $F_1$, U-Union $F_1$, SN-Sweet Nugget $F_1$; I - Irrigation: Control– treatment without irrigation, IR – 50% - treatment reduced norm irrigation, IR -100% - treatment full irrigation norm. SD – Sowing date: I - end of April/beginning of May – July; II - mid-July. TS- total sugars; RS – reducing sugars; IS – invert sugars; Suc- sucrose. Tukey's test (different letters indicate significant differences).

In general, the results indicate that on the second date of sowing, an increase in total sugars and other types is observed in most treatments, which can be attributed to the cumulative effect of metabolic processes during ripening and to interactions with soil moisture. These data suggest that the Sweet Nugget hybrid has the best biochemical properties for specific industrial applications due to its high sugar content. Enterprise and Union hybrids showed greater stability but significantly lower potential for sugar accumulation, regardless of the irrigation norm applied. In conclusion, the Sweet Nugget hybrid stands out as a high-quality genotype in terms of nutritional value and fruit sweetness.

In the second year of the research (Table 4b), the superiority of the hybrid Sweet Nugget in relation to Enterprise and Union continues in the view of all types of sugar. Sweet Nugget hybrid reaches average total sugar levels of over 40% in control conditions on the first sowing date, which is significantly higher than those of the other two hybrids, whose average levels range from 8% to 15%. This indicates that genotype is the determining factor in sugar accumulation, with the Sweet Nugget hybrid genetically predisposed to a high carbohydrate content. Irrigation (treatments IR 50% and IR 100%) significantly affects the chemical composition, but this influence is not linear in all hybrids. In the Sweet Nugget hybrid during the first sowing date, the control treatment recorded a higher total sugar content (40.39%) than the treatments with applied irrigation norms (about 21%). This suggests that moderate stress may stimulate sugar concentration due to a reduction in tissue hydration or plant metabolic response.

Table 4b. Average values of sweet corn hybrid on the content of different types of sugar in two sowing dates for second year research period (2023).

| | | I - SD | | | | II - SD | | | |
|---|---|---|---|---|---|---|---|---|---|
| H | I | TS (%) | RS (%) | IS (%) | Suc (%) | TS (%) | RS (%) | IS (%) | Suc (%) |
| E $F_1$ | Control | $13.27^{efgh}$ | $6.01^{fgh}$ | $7.20^{defgh}$ | $6.83^{defgh}$ | $16.25^{e}$ | $10.40^{cd}$ | $5.83^{defghi}$ | $5.54^{defghij}$ |
| | IR 50% | $8.06^{lmn}$ | $2.36^{ij}$ | $5.65^{fghi}$ | $5.38^{defghij}$ | $13.50^{efgh}$ | $6.08^{fgh}$ | $8.39^{defg}$ | $7.99^{def}$ |
| | IR 100% | $9.39^{ijklmn}$ | $3.25^{hij}$ | $6.19^{defghi}$ | $5.90^{defghij}$ | $16.40^{e}$ | $12.26^{abc}$ | $4.18^{hi}$ | $3.99^{ghij}$ |
| | **Average** | **10.24** | **3.87** | **6.35** | **6.04** | **15.38** | **9.58** | **6.14** | **5.84** |
| U $F_1$ | Control | $11.35^{hijk}$ | $7.62^{def}$ | $3.45^{i}$ | $3.28^{ij}$ | $12.31^{ghi}$ | $3.38^{hij}$ | $8.93^{de}$ | $8.48^{de}$ |
| | IR 50% | $7.33^{mn}$ | $3.11^{hij}$ | $3.16^{i}$ | $3.03^{j}$ | $11.96^{hij}$ | $3.75^{ghij}$ | $8.36^{defg}$ | $7.96^{def}$ |
| | IR 100% | $7.23^{mn}$ | $4.12^{ghij}$ | $3.13^{i}$ | $2.97^{j}$ | $8.25^{klmn}$ | $2.44^{ij}$ | $5.80^{efghi}$ | $5.63^{defghij}$ |
| | **Average** | **8.64** | **4.95** | **3.25** | **3.09** | **10.84** | **3.19** | **7.70** | **7.36** |
| SN $F_1$ | Control | $40.39^{a}$ | $14.56^{a}$ | $26.01^{c}$ | $24.71^{c}$ | $37.74^{ab}$ | $11.53^{abc}$ | $26.34^{bc}$ | $25.04^{bc}$ |
| | IR 50% | $21.10^{d}$ | $12.03^{abc}$ | $9.07^{d}$ | $8.61^{d}$ | $37.93^{ab}$ | $8.13^{def}$ | $30.19^{a}$ | $28.68^{a}$ |
| | IR 100% | $21.54^{d}$ | $14.66^{a}$ | $7.98^{defg}$ | $7.59^{def}$ | $27.59^{c}$ | $3.70^{ghij}$ | $23.91^{c}$ | $23.13^{c}$ |
| | **Average** | **27.68** | **13.75** | **14.35** | **13.64** | **34.42** | **7.70** | **26.81** | **25.62** |

H- Hybrid: E-Enterprise $F_1$, U-Union $F_1$, SN-Sweet Nugget $F_1$; I - Irrigation: Control– treatment without irrigation, IR – 50% - treatment reduced norm irrigation, IR -100% - treatment full irrigation norm. SD – Sowing date: I - end of April/beginning of May – July; II - mid-July. TS- total sugars; RS – reducing sugars; IS – invert sugars; Suc- sucrose. Tukey's test (different letters indicate significant differences).

However, in the Enterprise hybrid, 100% irrigation during the second sowing date results in a slight increase in total sugars and a significant increase in reducing sugars (12.26%) compared with the control. In the Sweet Nugget hybrid, the sucrose content is dominant and follows the trend of total sugars. Interestingly, the values for sucrose and invert sugars are often close, which indicates a balanced activity of the invertase enzyme. Hybrid Union shows the least variation between treatments, with the lowest average sugar values, making it more stable but with a less sweet quality.

There are apparent differences in sowing dates, suggesting a significant interaction between external environmental factors (temperature, isolation) and the irrigation norm. The Sweet Nugget hybrid stands out as the best option for industrial use or direct consumption due to its high sucrose and total sugar content. Although irrigation affects yield, these data suggest that excessive irrigation (IR 100%) in specific genotypes can lead to "dilution" of sugar content. In contrast, in others, it can help maintain metabolic processes that accumulate sugar (depending on the sowing date).

The heatmap visually shows the strength of correlation, i.e. the linear coefficient of influence between pairs of traits (Figure 2). All established correlations are positive. The strongest correlations were found between total ear weight and kernel weight (0.97) and kernel weight and shelling percentage (0.76), while the weakest were between total kernel yield and shelling percentage (0.49). The analyses provide practical significance, especially in the context of sustainable production of sweet corn hybrids with improved productive traits, on which the yield significantly depends.

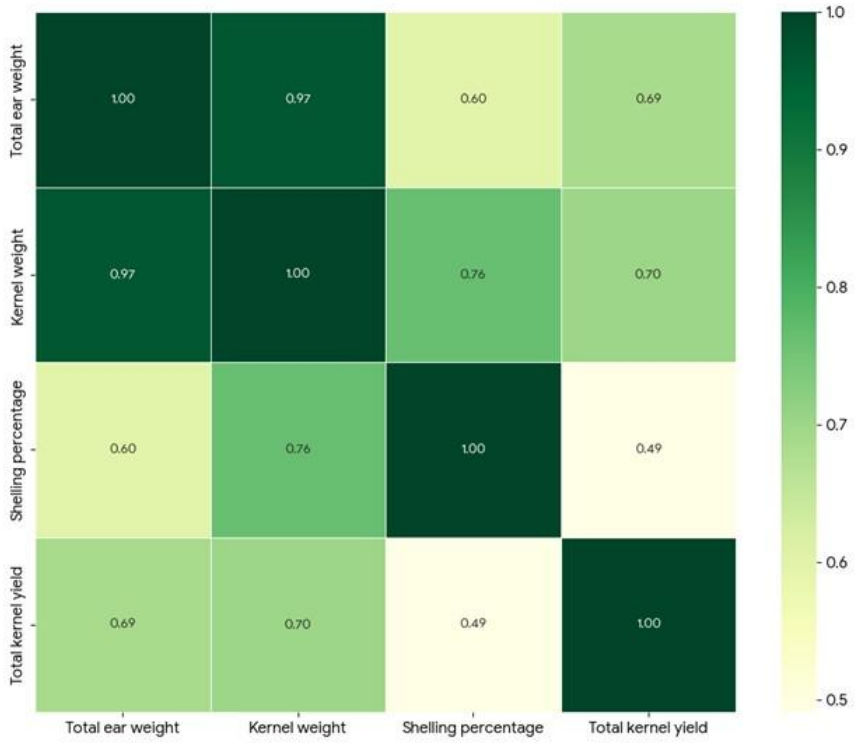



Figure 2. Heatmap for productive traits of sweet corn hybrids

Figure 3 shows a heatmap of different types of kernel sugars, with an extreme correlation (1.0) between invert sugars and sucrose, indicating that these two traits are directly dependent on each other. A strong positive relationship was observed between total sugars and sucrose (0.93), as well as between total sugars and invert sugars, indicating that these components account for the largest share and exert the most significant influence on total sugars. Reducing sugars show the weakest correlation with other traits, suggesting that their levels change independently of sucrose and invert sugars.

The results of the two-year research indicate the key influence of production factors on the yield and sugar level of different sweet corn hybrids. The research confirms that the application of adequate agricultural techniques is crucial for achieving top kernel quality and maximum productivity.

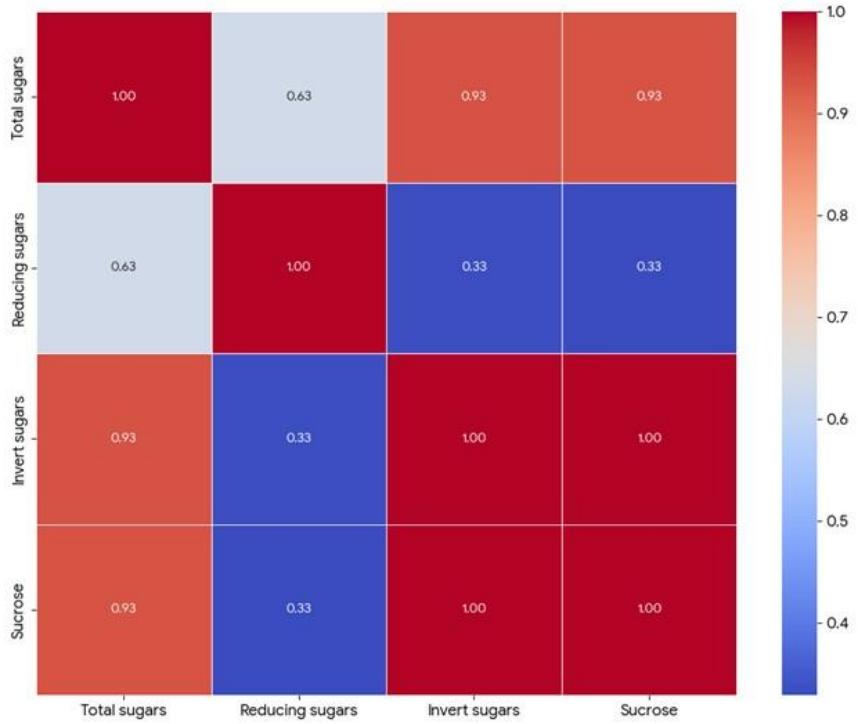



Figure 3. Heatmap for the content of different sugars in the kernel of sweet corn hybrids

## 4. DISCUSSION

The results of the two-year study, processed by joint analysis of variance, confirm the significant influence of the year, sowing date (Rahmani et al., 2016; Dekhane and Dumbre, 2017; Shibzukhov et al., 2021), irrigation norm (Badr et al., 2021) and hybrid selection (Haidar, 2018) on yield components and sweet corn sugar content. All observed factors individually, as well as the high-order interaction (year x sowing time x hybrid x irrigation), showed a statistically significant effect on most of the tested traits, which indicates a complex interdependence of genetic and external factors (Stojiljković et al., 2025b), which is significant for adapting cultivation technology in the changing agroecological conditions of Serbia, where the years 2022 and 2023 were warmer than the multi-year average with irregular precipitation precipitation.

Hybrid Enterprise stood out in terms of yield, with the highest ear weight, kernel weight, and total kernel yield, especially at the second sowing date under full or reduced irrigation. This is consistent with the findings of Srdić et al. (2016), who reported that genotype influences the yield of fresh sweet corn ears. That the yield of corn kernels is influenced by numerous environmental factors, such as climatic conditions, water availability and soil condition, was established by earlier research (Biberdžić et al., 2018; Rajičić et al., 2025; Stojiljković et al., 2025b). Soil moisture status is important for maintaining optimal maize yield. The high productivity of the Enterprise hybrid under reduced irrigation indicates a good efficiency of water use, which is especially important in conditions of limited water resources, as determined in the research of Ertek and Kara (2013), about a smaller drop in yield in specific genotypes in conditions of water deficit.

In the second sowing date (mid-July, after the wheat harvest), higher average yields were achieved in all hybrids, despite variations in rainfall between years. This can be attributed to better alignment of meteorological conditions with critical stages of plant development (flowering and kernel filling), as well as to more efficient irrigation use in the later production cycle. A similar effect of a later sowing date on yield was also observed by Kara et al. (2013).

In terms of sugar content, the Sweet Nugget hybrid stood out with total sugar levels over 40% (40.39% in the control in the second year, the first sowing date), as well as sucrose and invert sugars, making it ideal for industrial use or direct consumption due to its sweetness. The highest sugar content was recorded in the control (natural wetting), where mild water stress stimulates sugar concentration due to a decrease in tissue hydration and the plant's metabolic response, which is in accordance with Dicket and Tracy (2001) and Tupajić et al. (2024b) who determined a higher sugar content under conditions of reduced irrigation. Excessive irrigation in this hybrid leads to "dilution" of the sugars, while in the Enterprise hybrid, a full irrigation norm can slightly increase the content of reducing sugars. Hybrids Enterprise and Union had lower values (8–15%), with stability but lower potential, and in the case of Enterprise, the full norm in the second

sowing date slightly increased reducing sugars (12.26%). Differences in the responses of hybrids to irrigation confirm the significance of the genotype × irrigation × sowing time interaction, as previously highlighted by Metha et al. (2017) and Subaedah et al. (2021), in which genotype affects sucrose content in the range of 20–22° Brix. The differences in the response of the hybrids to the irrigation norm confirm the importance of the genotype x irrigation interaction, which was previously noted in the results of Metha et al. (2017). Correlation heatmaps show strong positive relationships between ear weight and kernel weight (0.97), as well as between total sugars, sucrose, and invert sugars, consistent with the results of Ganesan et al. (2017). These relationships emphasize that improving productive traits directly affects yield, while the balance between sucrose and invert sugars determines overall kernel sweetness. Combined analysis of the two-year research results allowed a more reliable assessment of interactions, emphasising that, for maximum yield, Enterprise should be chosen with a full or reduced norm in the second sowing date. At the same time, Sweet Nugget provides better quality under stress conditions. Future research should focus on the influence of rainfall distribution and temperature on irrigation efficiency across different regions to improve the sustainable production of sweet corn.

## 5. CONCLUSION

The results of the two-year study showes that all individual factors (year, sowing date, hybrid, irrigation norm) and the high-order interaction (year × sowing date × hybrid × irrigation) significantly influences yield components and sugar content in sweet corn kernels. Hybrid Enterprise achieved the highest yield values (ear weight, kernel weight, and total yield), especially at the second sowing date under full or reduced irrigation, demonstrating high water-use efficiency and adaptability. The second sowing date (mid-July) enabled a better expression of the genetic potential of all hybrids, despite annual rainfall variations.

The Sweet Nugget hybrid stood out for the highest content of total sugars (over 40%), sucrose and invert sugars, especially in conditions of natural moistening or slight water deficit in the first sowing date, while excessive irrigation can reduce the concentration of sugar in this genotype.

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