*Ivana Ligda[1], Ivana Varga[1], Goran Herman[1], Dario Iljkić[1], Manda Antunović[1]* **Professional paper**

# Relationship between sugar beet yields, sucrose content and weather conditions in Eastern Croatia

***Abstract***

*This study analyzes sugar beet root yield, and sucrose content in Eastern Croatian in the period from 2018 to 2023. All agrotechnical measures were carried out properly. The sugar beet was sown in the optimal terms, from mid-March to the beginning of April. The relationship between temperatures, root yield, and plant protection in sugar beet production is critical for optimizing crop outcomes. The highest sugar beet root yield was in 2021 (95.6 t ha$^{-1}$) with the highest sucrose content (17.6%). In 2023, yields were low (40.8 t ha$^{-1}$), likely due to high summer temperatures. The average root yield over six years was 75.0 t ha$^{-1}$ with an average sucrose content of 15.4%. In general, these research outcomes confirmed that the balance between appropriate sowing times, temperature management, and plant protection measures is crucial for maximizing root yield and sugar content.*

***Key words:*** *temperatures, root yield, summer, sowing, plant protection, rainfall*

## Introduction

Climatic conditions have been a crucial factor determining the success of crop cultivation. However, as agriculture has evolved, human activity has increasingly emerged as a significant—and often detrimental—force in shaping the agricultural environment. In Europe, sugar beet is usually sown between March and April and Harvested in autumn.

There are numerous studies that indicate that sugar beet is sensitive to water supply in terms of yield, dry matter accumulation, leaf growth, and beetroot formation (Okom et al., 2017; Varga et al., 2020; 2024). According to McEntee (1983), for Ireland dry conditions in the period from sowing to emergence as well as windy conditions in April and May can influence the final sugar beet root yield.

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Draycott (2006) states that, in Western Europe and North America, most sugar beet root crops are produced from quality monocot seeds with 95% germination. It should be emphasized that sugar production takes place already in the first year when the thickened root is removed. The root itself contains an average of 16% (FAO, 2009) and even up to 20% of sugar, and the extraction percentage is 40 to 80% (Draycott, 2006).

Table sugar is obtained by further processing of sucrose sugar. In addition to the above, sugar beet by-products are extremely important in livestock feeding: beet slices, molasses, and vinasse (Zicari et al., 2019). According to FAO data (2022), the most sugar beet is produced in Europe (predominantly in the northern parts due to a more suitable climate), followed by North America and Asia. Analyzing production by country, the dominant producers are: Russia, France, Germany, Turkey, and the USA. According to the data of the National Bureau of Statistics (2023), in the period from 2018 to 2022, a negative trend of areas sown under sugar beet is visible, and thus the total production is also decreasing. In 2022, 572,186 tons were produced with a yield of 64.4 tons per hectare.

Ebmeyer and Hoffmann (2022) reported that when the water supply for sugar beet was unlimited, water consumption and growth rate were closely aligned, suggesting that sugar beet's water demand is driven by its growth rate. Authors furthermore accelerate the impact of early drought stress, particularly during the period of the highest growth rate, which caused the most significant reductions in yield. Optimal sowing temperatures range around 5°C for successful germination, with higher temperatures during the growing season promoting leaf growth and sugar accumulation. However, extreme summer heat can stress plants, reducing root yield and sucrose content. This study aimed to detailed analysis of the weather conditions and agrotechnical measures on the sugar beet root yield and quality.

## Material and methods

### *Experimental site*

The research was conducted from 2018 to 2023 in Eastern Croatia at location Jelisavac Croatia. The soil properties are shown in table 1. The sowing (Picture 1a) was done at the optimum time (Table 2).

In all production years, the distance between rows was 45 cm, and the distance between the seeds within the rows was 20 cm (Picture 1 b).

**Table 1.** Results of soil chemical analysis in 2022
**Tablica 1.** Rezultati kemijske analize tla u 2022. godini

| Parameter | Result | Unit. measures | Interpretation |
|---|---|---|---|
| pH KCl | 5.13 | - | Acidic reaction |
| pH $H_2O$ | 6.24 | - | - |
| Hydrolytic acidity | 3.85 | Cmol(+)/kg | Calcization useful, not necessary |
| Humus | 2.30 | % | Moderate/medium humus soil |
| Al- | 11.11 | mg/100g | Poor supply |
| Al- 0 | 30.96 | mg/100g | Richly supplied |

**Table 2.** The time of sowing and sugar beet hybrids included in the study
**Tablica 2.** Vrijeme sjetve i hibridi šećerne repe uključeni u istraživanje

| Year | Time of sowing | Hybrid | Sowing rate (U/ha) |
|---|---|---|---|
| 2018 | mid–March | Terranova | 1.10 |
| 2019 | mid-March | Terranova | 1.10 |
| | | Belamie | |
| 2020 | second half of March | Smart Belamia | 1.15 |
| 2021 | end of March | Smart Rosada | 1.10 |
| | | Smart Djerba | |
| 2022 | end of March | Smart Rosada | 1.15 |
| 2023 | end of March-beginning of April | Samrt Perla | 1.10 |
| | | Samrt Rasada | |


**Picture 1.** Sugar beet sowing (on the left) and the distance between the seeds (on the right)
**Slika 1.** Sjetva šećerne repe (lijevo) i razmak između sjemenki (desno)

***Plant protection***
The insecticide Force (Teflutrin) was immediately incorporated in the amount of 7 kg ha$^{1}$, with sowing for protection against wireworms and whiteflies. A total of four treatments were performed against weeds and pests in the sugar beet crop (table 3 and table 4). Weed protection was applied for the first time after emergence (in the cotyledon stage) at the beginning of April. The second treatment was performed 10 to 14 days after the first treatment, i.e. in mid-April. The third treatment was performed 10 days after the second protection (at the end of April). The last, i.e. the fourth, treatment was performed at the beginning of May (10 to 15 days after the third treatment). In the production years 2020 - 2023, means for protection against weeds and pests were applied 3 times a year (Table 4).

**Table 3.** Sugar beet protection against weeds and pests in 2018 and 2019
**Tablica 3.** Zaštita šećerne repe od korova i štetnika u 2018. i 2019. godini

| Time of application | Means | Active substance | Quantity (l ha-1) |
|---|---|---|---|
| 3 – 6 April | Betanal Experet | Desmedifam<br>Etofumesat<br>Fenmedifam | 0.80 |
| | Lontrel 300 | Clopyralid | 0.15 |
| | Chromorel D | Klorpirifos<br>Cipermetrin | 1.00 |
| 16 – 19 April | Betanal Expert | Desmedifam<br>Etofumesat<br>Fenmedifam | 0.90 |
| | Lontrel 300 | Clopyralid | 0.17 |
| 28 – 30 April | Betanal Expert | Desmedifam<br>Etofumesat<br>Fenmedifam | 1.00 |
| | Lontrel 300 | Clopyralid | 0.17 |
| 5 – 9 May | Select Super | Kletodim | 0.70 |
| | Lontrel 300 | Clopyralid | 0.17 |

**Table 4.** Sugar beet protection against weeds and pests 2020 – 2023
**Tablica 4.** Zaštita šećerne repe od korova i štetnika 2020. – 2023

| Time of application | Means | Active substance | Quantity (l ha-1) |
|---|---|---|---|
| 2 – 7 April | Conviso one | Foramsulfuron<br>Tienkarbazon-methy | 0.50 |
| | Lontrel 300 | Clopyralid | 0.17 |
| | Karate Zeon | Lambda-cihalotrin | 0.20 |
| 15 – 21 April | Conviso one | Foramsulfuron<br>Tienkarbazon-methy | 0.50 |
| | Lontrel 300 | Clopyralid | 0.20 |
| 26 April - 3 May | Select Super | Kletodim | 0.50 |
| | Lontrel 300 | Clopyralid | 0.20 |

At the same time, sugar beet crops were treated with different agents against diseases in the production years from 2018 to 2023 (table 5, table 6).

**Table 5.** Sugar beet protection against diseases in 2018 and 2019
**Tablica 5.** Zaštita šećerne repe od bolesti u 2018. i 2019. godini

| Time of application | Product | Active substance | Quantity |
|---|---|---|---|
| 10 June | Sphere | Trifloxystrobin, Ciproconazole | 0.35 l $ha^{-1}$ |
| | Moisturizer Inex | Fatty alcohol ethoxylate | 0.20 l $ha^{-1}$ |
| | | Polydimethylsiloxane | |
| | Impact 25 SC | Flutriafol | 0.50 l $ha^{-1}$ |
| 2 July | Bravo 720 SC | Chlorothalonil | 0.40 l $ha^{-1}$ |
| | Moisturizer Inex | Fatty alcohol ethoxylate | 0.20 l $ha^{-1}$ |
| | | Polydimethylsiloxane | |
| 23 July | Sphere | Trifloxystrobin, Ciproconazole | 0.35 l $ha^{-1}$ |
| | Moisturizer Inex | Fatty alcohol ethoxylate | 0.20 l $ha^{-1}$ |
| | | Polydimethylsiloxane | |
| | Rias | Difenkonazol, Propikonazo | 0.30 l $ha^{-1}$ |
| 10 August | Penncozeb 75 DG | Mancozeb | 2 kg/ha |
| | Moisturizer Inex | Fatty alcohol ethoxylate | 0.20 l $ha^{-1}$ |
| | | Polydimethylsiloxane | |
| 25 August | Impact 25 SC | Flutriafol | 0.50 l $ha^{-1}$ |
| | Duett Ultra | Methylthiophanate | 0.90 l $ha^{-1}$ |
| | | Epsoxiconazole | |
| | Moisturizer Inex | Fatty alcohol ethoxylate | 0.20 l $ha^{-1}$ |
| | | Polydimethylsiloxane | |

**Table 6.** Plant protection against diseases in 2020 - 2023
**Tablica 6.** Zaštita bilja od bolesti 2020. - 2023

| Time of application | Name of the product | Active substance | Quantity |
|---|---|---|---|
| 15 June | Propulse | Fluopiram, Prothioconazole | 1.2 l $ha^{-1}$ |
| | Neoram WG | Copper oxychloride | 2.5 kg/ha |
| | Wetting agent Sticman | Styrene butadiene co-polymer | 0.2 l $ha^{-1}$ |
| | | Trisiloxane organosilicon copolymers | |
| | Spyrale | Fenpropidine, Difenconazole | 1.0 l $ha^{-1}$ |
| | Neoram WG | Copper oxychloride | 2.5 kg/ha |

| Time of application | Name of the product | Active substance | Quantity |
|---|---|---|---|
| 6 July | Wetting agent Sticman | Styrene butadiene co-polymer | 0.2 l ha$^{-1}$ |
| | | Trisiloxane organosilicon copolymers | |
| 27 July | Propulese | Fluopiram, Prothioconazole | 1.2 l ha$^{-1}$ |
| | Neoram WG | Copper oxychloride | 2.5 kg/ha |
| | Wetting agent Sticman | Styrene butadiene co-polymer | 0.2 l ha$^{-1}$ |
| | | Trisiloxane organosilicon copolymers | |
| | Spyrale | Fenpropidine, Difenconazole | 1.0 l ha$^{-1}$ |
| | Revycare | Revysol, Pyraclostrobin | 1.0 l ha$^{-1}$ |
| 27 August | Wetting agent Sticman | Styrene butadiene co-polymer | 0.2 l ha$^{-1}$ |
| | | Trisiloxane organosilicon copolymers | |

***Harvest***

Sugar beet harvest was carried out with self-propelled harvesters (Picture 2). In production years 2018 and 2019, harvest was at the end of September, in 2020 and 2021 at the end of October, while in 2022 harvest was done in mid–November, and in 2023 harvest began in mid-October. Sugar beets were stacked in piles in landfills in the field. After harvest, the sugar beet should be transported as soon as possible for further processing in the sugar factory in order to clean and remove impurities.


**Picture 2.** Harvest of sugar beet
**Slika 2.** Vađenje šećerne repe

## Results and discussion

Data on mean monthly temperatures in the period and total average precipitation amounts from 2018 to 2023 was used from State hidrometeorological Insitute (2024) for Našice, which is 5.4 km air distance form the Jelisavac location.

Average monthly air-temperature (°C) from 2018 to 2023 of Našice meteorological station (5.4 km air distance from Jelisavac) (State Hydrometeorological Institute, 2024). At the time of sugar beet sowing in 2018, i.e. in the second decade of March, the average temperature was 7.1°C. The specified temperature is above the necessary 6 °C for faster and complete germination of sugar beet. High temperatures characterized spring, and the duration of such temperatures continued until the end of August. At the time of harvest during the third decade of September, the temperatures were

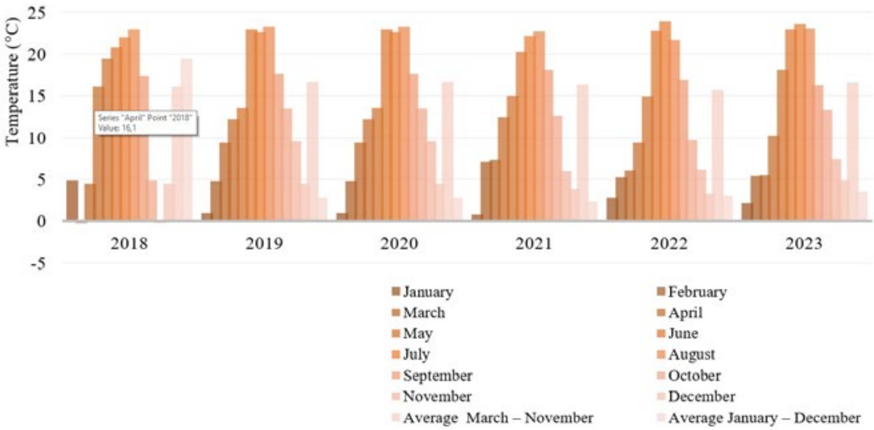


**Figure 1.** Average monthly air-temperature (∞C) from 2018 to 2023 of Našice meteorological station (5.4 km air distance from Jelisavac) (State Hydrometeorological Institute, 2024)

12.3°C (Figure 1). During the sowing of sugar beet in the production year 2019, the average temperature in the second decade of March was 7.8 °C, which is slightly higher than the 2018 year (Figure 1). The spring was warm, high temperatures marked the summer months, and in extraction time during the third decade of September, temperatures were higher than average for that time of the year. In the 2020 production year, during the sowing of sugar beet, the temperature was significantly higher in the second decade of March than in previous years. The temperatures in the second decade of March 2020 were 9.8 °C. The weather was warm, and the highest temperatures were in July and amounted to 24.1 °C. Due to the high temperatures during September 2020, harvestbegan towards the end of the third decade of October. The roots was still growing in the fall and produced a higher sugar content. Furthermore, in the second decade of March 2021, the temperature was 5.2 °C, which is lower than the optimum temperature for sowing. April 2021 was cool, but high temperatures were present until the second decade of August. During sugar beet harvesting during the third decade of October, temperatures were significantly lower than in September and amounted to only 7.7 °C. During the sowing of sugar beet in 2022, i.e. in the second decade of March, temperatures were extremely low and the average temperature in the second decade of March was only 3.8 °C. Due to low temperatures, sowing only started at the end of March. In May, the air temperature increased significantly, and the intensity of the increase in air temperature continued during the summer. The summer was warm and characterized by the presence of high temperatures. This tendency of high temperatures lasted until the end of August. In autumn, high temperatures continued, and therefore the harvest was postponed and did not start until the beginning of November. During harvest in the first decade of November, the weather was warm and favorable for extraction. The temperatures for sowing sugar beet in the 2023 production year, during the second decade of March, was optimal, but during the phase of intensive leaf growth, there were high temperatures during the summer months, especially during July when the average temperature was 23.7 °C. Temperatures during the fall were high, so beet harvesting started in mid-October 2023. Analyzing the amount of precipitation in 2018, it is observed that in the second decade of March, during the sowing time, a larger amount of precipitation fell and the sowing period was extended (Figure 2). The highest average amount of precipitation fell during June, while a small amount of precipitation fell during autumn, during beet harvesting in the first decade of October 2018.

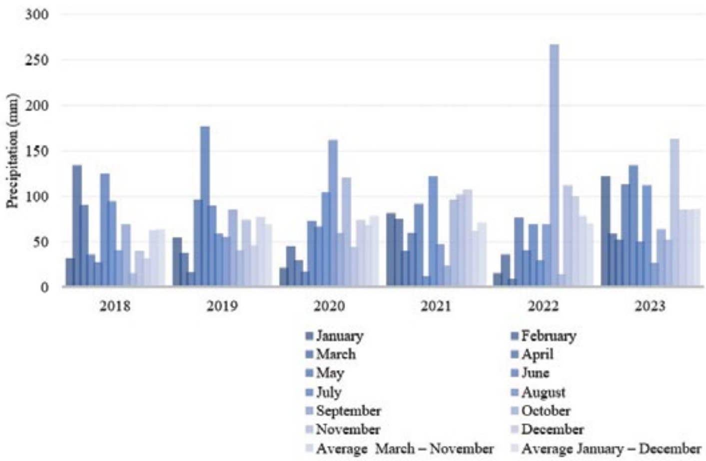


**Figure 2.** Average monthly precipitations (mm) from 2018 to 2023 of Našice meteorological station (5.4 km air distance from Jelisavac) (State Hydrometeorological Institute, 2024)
**Slika 2.** Prosječna mjesečna količina oborine (mm) od 2018. do 2023. godine meteorološke postaje Našice (5,4 km zračne udaljenosti od Jelisavca) (Državni hidrometeorološki zavod, 2024.)

In the 2019 production year, during sowing in the second decade of March, the amount of precipitation was only 1.5 mm (Figure 2). The summer months were marked by precipitation, which in addition to high temperatures favored the development of the disease *Cercospora beticola* Sacc., as was the case in the previous year 2019. During the sugar beet harvest, the amount of precipitation was extremely high, which made the harvest of sugar beet roots and the campaign itself much more difficult and prolonged in 2019. A large amount of precipitation was recorded during the summer months in 2020. During the sowing of sugar beet during the second decade of March, there was no precipitation at all. A large amount of precipitation lasted from July until October. The extraction of beets was characterized by a lot of rainfall, the extraction took longer and became more difficult.

Sowing in 2021 started at the end of March. There was enough precipitation in spring, but the highest average amount of precipitation was during July (145.4 mm). June and August were without significant amounts of precipitation. The harvest of sugar beet roots at the end of October was marked by higher amounts of precipitation (96.7 mm).

In the production year 2022, the absence of precipitation was observed, and at the very beginning of the growing season and in the spring (9.1 in March 2022). Sugar beet harvest could not start in September 2022 due to the fact that there was a significant amount of precipitation throughout September (266.7 mm). Therefore, the harvest of sugar beet roots began in the third decade of October and the first decade of November.

Furthermore, the year 2023 was marked by an exceptionally rainy. The sowing was done at the end of March. The rainy season, with large amounts of precipitation, continued throughout the spring until July. Large amounts of precipitation led to the rotting of beets. August, September, and October were characterized by very little rainfall (27.1, 64,0, and 53.2 mm, respectively), and beet harvest began in the second decade of October.

The average sugar beet root yield in the present study was 75.0 t/ha and a sucrose content of 15.4 % (Table 7). Lower root yields and sugar content of sugar beet were in 2018 and 2019, due to disease *Cercospora beticola* Sacc., but also to agroclimatic conditions. Significant leaf regrowth occurred, which is why beet harvesting began at the end of September, immediately after the sugar factory campaign started. The progress in controlling *Cerco-*

*spora beticola* Sacc. occurred in 2020, when sugar beet protection was successful, resulting in increased root yield and quality compared to 2018 and 2019. Harvesting began only at the end of October and early November because the sugar beet roots were healthy, leaf regrowth did not occur, and favorable climatic conditions persisted throughout October. The average root yield in 2020 was 88.2 t ha$^{-1}$, with an average sugar content of 16.0%.

**Table 7.** Sugar beet root (t ha$^{-1}$) yield and sucrose content (%)
**Tablica 7.** Prinos korijena šećerne repe (t ha$^{-1}$) i sadržaj saharoze (%)

| Year | Root yield (t ha$^{-1}$) | Sucrose content (%) |
|---|---|---|
| 2018 | 71.4 | 15.0 |
| 2019 | 73.7 | 14.1 |
| 2020 | 88.2 | 16.0 |
| 2021 | 95.6 | 17.6 |
| 2022 | 80.4 | 15.3 |
| 2023 | 40.8 | 14.2 |
| Average | **75.0** | **15.4** |

The highest sucrose content was in 2021 (17.6 %), when also the root as the highest, weighing over 2 kilograms (Picture 3.). In the 2021 production year, beet harvesting began at the end of October (the beets were healthy), with an average root yield of 95.6 t ha$^{-1}$ and a sugar content of 17.6%. The highest yield and sugar content were achieved in 2021.

**Picture 3.** Sugar beet root in 2021
**Slika 3.** Korijen šećerne repe u 2021

The year 2022 was marked by an extremely dry summer, followed by an exceptionally rainy autumn. As a result, there was significant leaf regrowth and a reduction in sucrose content. Harvesting began in mid-November to maximize root yield due to the autumn rains. The average root yield in 2022 was 80.4 t ha$^{-1}$, with an average sugar content of 15.3% (Table 7). In the spring of 2023, there was excessive rainfall, accompanied by heavy showers and occasional hail, while the summer months experienced severe drought. Extremely high temperatures during the summer and September caused the sugar beet roots to shrivel. These factors resulted in “rubber” beets and crop failure. Yields and quality were low, 40.8 t ha$^{-1}$, with an average sugar content of 14.2%. Harvesting began in mid-September.

Desheva and Valchinova (2024) stated that environmental conditions have high impact on yield formation. Weather conditions play a crucial role in determining sugar beet yield and sucrose content (Uçan and Gençoğlan, 2004, Hoffman et al., 2009). Sugar beet is particularly sensitive to temperature, water availability, and wind, which influence growth phases such as germination, leaf development, and root formation. In the Easter part of Croatia, it is specific the hot summers, often with the lack of rainfall (Salaić et al., 2024). Sugar beet yields and sucrose content in Eastern Croatia are significantly influenced by weather conditions, particularly rainfall and temperature. Optimal growth is achieved with sufficient rainfall and moderate temperatures, while drought and high temperatures can adversely affect both yield and sugar content. A study conducted in Eastern Croatia during 2014 and 2015 highlighted these effects. In 2014, favourable weather with adequate rainfall and moderate temperatures resulted in an average root yield of 98.9 t/ha and a sucrose content of 13.15%. Conversely, 2015 experienced higher temperatures and reduced rainfall, leading to a decreased average root yield of 70.9 t/ha, though the sucrose content increased to 15.50% (Varga et al. 2021). This suggests that while drought conditions may reduce overall yield, they can sometimes lead to higher sucrose concentrations in the roots. For sugar beet, the drought and high-temperature stresses during summer, especially in August, can reduce sugar beet yield and quality. These findings underscore the critical role of weather conditions in sugar beet cultivation in Eastern Croatia. Adequate rainfall and moderate temperatures are essential for maximizing both yield and sucrose content, while drought and high temperatures can significantly impede production. Abu-Ellail et al. (2024) highlights the significant agricultural challenge posed by water scarcity in dry and semi-arid regions, specifically in the context of sugar beet cultivation under water deficit conditions. The authors stated that there were significant interactions between the sugar beet varieties and the water deficit levels, suggesting that the varieties responded differently to drought stress, which emphasizes the importance of selecting drought-tolerant varieties for cultivation in water-scarce areas. In Turkey, Kiymaz and Ertek (2014) suggests that effective water management using class A pan evaporation can help optimize water use in sugar beet production. Fitters et al. (2022) did no found significant yield differences were observed between rainfed and irrigated treatments for sugar beet, which the authors explain that the lack of difference is likely due to the mild drought stress, which may not have been intense enough to induce major yield reductions.

For many years, sugar beet has provided significant financial profit despite the challenges it brings in production (Pavlů and Benešová, 2023). However, in recent years, the area under sugar beet cultivation in Croatia has drastically decreased. Many producers have abandoned sugar beet farming due to unprofitability and the impact of *Cercospora beticola* Sacc., which caused significant damage to crops, while the registered fungicides were ineffective in controlling the disease. With the registration of new fungicides, protection against the disease has improved, resulting in increased yields and sugar content.

## Conclusion

Sugar beet production requires great knowledge and the timely application of agricultural techniques to achieve high yields and digestion. It is important to observe a crop rotation of at least four years, as well as timely tillage, sowing, protection and fertilization. Advances in technology make the process more profitable, while sustainable practices reduce negative impacts on the environment. Although sugar beet once brought significant financial profit, in recent years production areas in the Republic of Croatia have been reduced due to unprofitability and diseases such as *Cercospora beticola* Sacc. The registration of new fungicides has improved crop protection, but more registrations are needed to reduce resistance.

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***Stručni rad***

### *Odnos između prinosa šećerne repe, sadržaja saharoze i vremenskih uvjeta u istočnoj Hrvatskoj*


***Sadržaj***

*U radu se analizira prinos korijena šećerne repe i sadržaj saharoze u istočnoj Hrvatskoj u razdoblju od 2018. do 2023. Svi agrotehnički zahvati provedeni su sukladno pravilima struke. Sjetva šećerne repe obavljena je u optimalnim rokovima, od sredine ožujka do početka travnja. Odnos između temperatura, prinosa korijena i zaštite bilja u proizvodnji šećerne repe ključan je za optimizaciju rezultata usjeva. Najviši prinos korijena šećerne repe zabilježen je 2021. godine (95,6 t ha$^{-1}$) s najvišim udjelom saharoze (17,6%). Godine 2023. prinosi su značajno pali (40,8 t ha$^{-1}$), vjerojatno zbog visokih ljetnih temperatura. Prosječni prinos korijena tijekom šest godina iznosio je 75,0 t ha$^{-1}$ s prosječnim udjelom saharoze od 15,4%. Općenito, ovi rezultati istraživanja potvrdili su da je ravnoteža između odgovarajućih rokova sjetve, upravljanja temperaturom i mjera zaštite bilja ključna za maksimiziranje prinosa korijena i sadržaja šećera.*


***Ključne riječi:*** *temperature, prinos korijena, ljeto, sjetva, zaštita bilja, oborine*