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Effect of agroecological factors of sugar beet (*Beta vulgaris* provar. *altissima* Doell.) cultivation in interaction with different genotypes and stimulating substances

Vplyv agroekologických faktorov na pestovanie repy cukrovej (*Beta vulgaris* provar. *altissima* Doell.) v interakcii s rôznymi genotypmi a stimulačne pôsobiacimi látkami

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ABSTRACT

A small-plot field experiment with sugar beet (*Beta vulgaris* provar. *altissima* Doell.) was focused on the monitoring of year weather conditions, selected genotypes and stimulating substances on the formation of quantitative and qualitative parameters. The experiment was carried out in the Center for Plant Biology and Ecology in Nitra during the years 2021 – 2022. The area is located at an altitude of 170 – 175 m above sea level in a corn production area with warm and dry climatic characteristics. The results of the experiment confirmed a statistically proven effect of the year conditions (P < 0.01) on the formation of quantitative and qualitative production parameters. In the range of monitored factors, agro-ecological conditions were more favourable in 2021, when a statistically higher root yield of 68.99 t/ha (+9.68 t/ha; rel. 16.32%) also sugar content of 16.75% (+0.68%; rel. 4.21%) were recorded. The statistical analysis confirmed a highly significant relationship (P < 0.01) between selected varieties and quantitative or qualitative production parameters. In the range of monitored genotypes, the highest root yield was recorded by Darvas 65.83 t/ha (+1.68 t/ha; rel. 2.62%) and the highest sugar content was indicated by Okapi 16.59% (+0.18%; rel. 1.11%). Implementation of stimulating substances with adaptogens positively affects the yield and sugar content of sugar beet. Stimulating preparations statistically affect (P < 0.01) the formation of monitored production parameters. The highest root yield of 67.40 t/ha (+7.56 t/ha; rel. 12.64%) and sugar content of 16.58% (+0.47%; rel. 2,91%) was indicated by variant 2 (Energeen Cleanstorm).

Keywords: biostimulants, sugar content, varieties, weather conditions, yield of root

ABSTRAKT

Maloparcelkový poľný experiment s repou cukrovou (*Beta vulgaris* provar. *altissima* Doell.) bol zameraný na monitoring vplyvu poveternostných podmienok, vybraných genotypov a stimulačne pôsobiacich látok na tvorbu kvantitatívnych a kvalitatívnych parametrov. Pokus bol realizovaný v Stredisku biológie a ekológie rastlín v Nitre počas rokov 2021 – 2022. Oblasť je lokalizovaná v nadmorskej výške 170 – 175 m nad morom, v kukuričnej výrobnej oblasti s teplou a suchou klimatickou charakteristikou. Výsledky experimentu potvrdili štatisticky vysoko preukazný vplyv ročníka (P < 0,01) na tvorbu kvantitatívnych i kvalitatívnych parametrov. V rozsahu sledovaných faktorov boli priaznivejšie agroekologické podmienky počas roku 2021, kde bola indikovaná štatisticky vysoko preukazne vyššia úroda 68,99 $t.ha^{-1}$ (+ 9,68 $t.ha^{-1}$; rel. 16,32 %) aj cukornatosť 16,75 % (+ 0,68 %; rel. 4,21 %). Štatistická analýza potvrdila vysoko preukazný vzťah medzi vybranými odrodami (P < 0,01) a kvantitatívnymi i kvalitatívnymi parametrami produkcie. V rámci sledovaných genotypov bola zaznamenaná najvyššia úroda buliev pri odrode Darvas 65,83 $t.ha^{-1}$ (+ 1,68 $t.ha^{-1}$; rel.

2,62 %) a najvyšší obsah cukru bol indikovaný pri odrode Okapi 16,59 % (+ 0,18 %; rel. 1,11 %). Implementácia stimulačne pôsobiacich látok s adaptogénnmi pozitívne formuje tvorbu úrody a obsah cukru repy cukrovej. Stimulačne pôsobiace prípravky mali štatisticky vysoko preukazný vplyv (*P* < 0,01) na formovanie sledovaných parametrov produkcie. Najvyššia úroda buliev 67,40 $t.ha^{-1}$ (+ 7,56 $t.ha^{-1}$; rel. 12,64 %) a cukornatosť 16,58 % (+ 0,47 %; rel. 2,91 %) bola indikovaná na variante 2 (Energeen Cleanstorm).

Kľúčové slová: biostimulátory, cukornatosť, odrody, poveternostné podmienky, úroda buliev

INTRODUCTION

Sugar beet (*Beta vulgaris* provar. *altissima* Doell.) is a crop with a great production potential. It has high photosynthetic efficiency and potential for the formation of organic components (Brar et al., 2015). In the temperate climate zone, it is the primary source of sucrose, which is used for sugar production (AlKahtani et al., 2021) and secondary products are used in animal feed and for bioenergy purposes (Abd El-Mageed et al., 2021).

In the context of the variability of agroecological conditions, a change in environmental factors occurs. Abiotic factors such as temperature and water stress (Abou-Elwafa et al., 2020), soil salinity (Abbasi et al., 2019), or biotic factors (Yu et al., 2020) are negatively correlated with morphological (Romano et al., 2013) and physiological aspects of the sugar beet production process (Flexas and Medrano 2002).

A key role in the intensification of quantitative and qualitative production parameters is the selection of adaptable varieties in accordance with the rationalization of agronomic practices (Brar et al., 2015). Resistant varieties of sugar beet are a tool for eliminating negative environmental factors and a rationalizing element of cultivation technology (Hesadi et al., 2015). Variability of morphological and anatomical features of the variety is modified by genetic predisposition (Rašovský et al., 2022) and a wide spectrum of complex of agronomic and environmental interactions (Ebmeyer et al., 2021).

In terms of production process optimization, innovative methods are implemented to maintain production stability and support the final harvest. New technologies eliminate the negative consequences of environmental aspects, increase plant productivity, and incites tolerance to environmental conditions. Stimulating substances and adaptogenic components are also an innovative tool that induce the production process, reduce temperature stress, and works as a catalyst of metabolic and physiological parameters (Thalooth et al., 2019).

Stimulating substances modify the formation of the root system, increase post-stress regeneration, induce the formation of quantitative and qualitative parameters, and eliminate the negative impact of environmental stress (Yakhin et al., 2017). Humic acids and adaptogenic components affect the yield and quality of sugar beet, have a beneficial effect on the physiological aspects of plants and positively affect sugar beet production (Thalooth et al., 2020). Stimulating preparations are an economic, effective, and renewable intensification element of agricultural production (Boraste et al., 2009).

The aim of this article was focused on monitoring the agroecological conditions of the year, the genetic predisposition of selected varieties and the application of stimulating preparations on the quantitative and qualitative production parameters of sugar beet in the warm lowland climatic region area of western Slovakia.

MATERIAL AND METHODS

Experimental area

A polyfactorial field experiment with sugar beet was carried out in 2021 – 2022 on a research-experimental basis in Center of Plant Biology and Ecology, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Nitra (48°19'23" N 18°08'58" E). The research base is in the geological interface of the loess sediments of Tribeč mountains and Podunajská panva lowland. The location of the area is at an altitude of 170 – 175 m above sea level. The area has a flat character with a slope to the south, with brown soil and clay to clay-loamy soil type (Šimanský, 2017).

The experimental base is classified into a corn production area with dry and warm climatic characteristics. Weather conditions during the observed vegetation periods were provided by agrometeorological station of Institute of Landscape Engineering, Faculty of Horticulture and Landscape Engineering in Nitra (Figure 1, Figure 2).

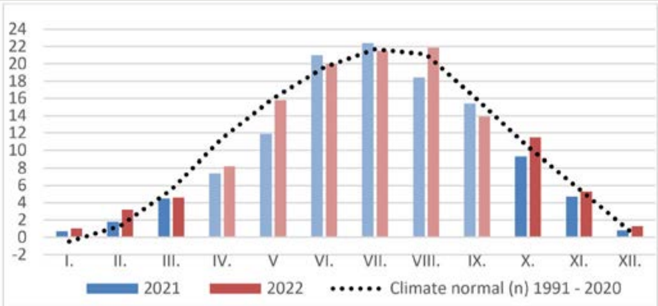

Figure 1. Mean air temperatures (°C) in the experimental period

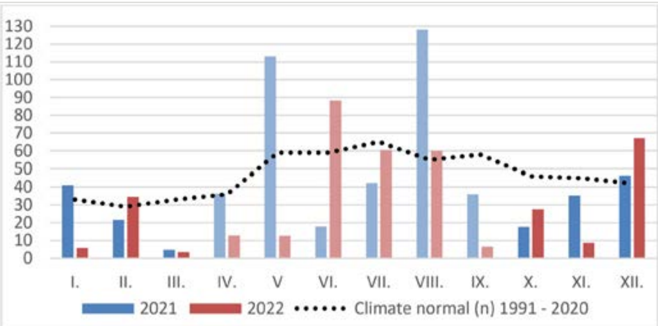

Figure 2. The sum of precipitation (mm) in the experimental period

Experimental methods

In the crop rotation system sugar beet was included after wheat (*Triticum aestivum* L.). After the pre-crop, the soil was stubble plowed, followed by medium-deep plowing with the simultaneous application of AMOFOS 15-52 fertilizer in a dose of 798 kg/ha (ACHP Levice, a.s., Levice, Slovak Republic) and manure (50 t/ha). Limestone 95% in a dose of 1.3 t/ha per year was used as a liming material for pH adjustment, and then deep plowing was carried out. Nitrogen fertilizer in the form of urea (46%) in a dose of 725 kg/ha (ACHP Levice, a.s., Levice, Slovak Republic) was applied in the spring during pre-sowing soil preparation. Fertilizer doses were determined based on agrochemical soil analysis using the balance method (Kováčik and Ryant, 2019) with conversion to an expected root yield of 70 t/ha.

Agrochemical analysis was carried out every year (Table 1). Ammoniacal and nitrate forms of nitrogen were determined colorimetrically using Nessler's reagent (Koch et al., 1924) and phenol-2,4-disulfonic acid (Pačuta et al., 2021). The Mehlich III test (Mehlich, 1984) was used to determine the content of phosphorus and potassium in the soil. The soil reaction was determined by using a 1-molar solution of potassium chloride (Kabala et al., 2016) and the humus content was calculated based on Tjurin's method (Kononova, 1975).

Cultivation technology

The cultivation of sugar beet was established by conventional technology (Jaggard and Qi, 2006). Before sowing, shallow tillage was carried out. Sowing was established with a 12-row seeding machine (row distance 0.45 m; distance in row 0.18 m) (Monosem, Largeasse, France). The experimental design was based on the method of randomized complete block design with three replicates (Ehrenbergerová, 1995). The trial plots had an area of 32.4 m^2 (6 m × 5.4 m). Sugar beet protection was based on methodological instructions for plant protection.

Harvesting was carried out in the technological maturity in the growth phase BBCH 47. Two representative rows were manually selected from each variant. The root yield was determined by conversion to units, tons per hectare (t/ha). Qualitative parameters were determined by Venema Analyzer IIIG (Venema Consulting, Groningen, Netherlands).

Experimental material

Varieties of sugar beet

The following genotypes were used in the experiment (SES Vander Have Group International BV):

Darvas: normal to late-type with high refining purity, has tolerance to water stress, high productivity, resistance to leaf diseases and good durability.

Table 1. Agrochemical soil analysis

Year	P	K	Ca	Mg	Humus content (%)
	mg/kg				
2020	94 $_G$	330 $_H$	2450 $_G$	295 $_H$	2.24
2021	85 $_S$	340 $_H$	2500 $_G$	304 $_{VH}$	2.27
	NO_3^--N	NH_4^+-N	IN	pH	Dry matter (%)
	mg/kg				
2021	10.2	9.6	19.8 $_S$	5.50 $_A$	88.10
2022	9.3	6.9	16.2 $_S$	5.90 $_{SA}$	87.40

IN – inorganic nitrogen; G – good content; S- suitable content; H – high content; VH – very high content; A – acidic pH; SA - slightly acidic pH

Bukovina: early to late-type with excellent resistance to diseases, above-average refining capacity, high sugar content and crop stability.

Okapi: normal to late-type with high resistance to rhizomania, medium to high level of root yield, with high sugar content and good storability.

Fertilizers with bioactive substances and adaptogens

Three stimulating fertilizers were included in the experiment, which were applied in three variants (Table 2).

Humix® Univerzál: special liquid foliar and soil fertilizer containing humic substances from Leonardite, macroelements and microelements that support the growth of the root system and increase the formation of quantitative and qualitative parameters (Agrocultur Bio s.r.o., Nitra, Slovakia).

- Humic substances min. 3.0% wt.
- Potassium (K_2O) min. 2.5% wt.
- Phosphorus (P_2O_5) min. 1.0% wt.
- Cu, Fe, B trace amounts in the chelate bond.
- pH 9 – 10.

Humix Bór (Boron): special liquid foliar and soil fertilizer intended for the nutrition of a wide range of field crops with higher boron requirements. It contains bioactive preparations based on humic substances from Leonardite, mixed with macronutrients and microelements (Agrocultur Bio s.r.o., Nitra, Slovakia).

- Humic substances min. 8.0% wt.
- Boron min. 2.5% wt.
- Cu, Zn, Fe trace amounts in the chelate bond.
- pH 7 – 9.

ENERGEN Cleanstorm: liquid leaf and soil preparation containing plant extracts with supporting adaptogens. It significantly increases plant resistance to drought and late frosts. It induces the process of photosynthesis in unfavourable weather conditions and increases the resistance of plants (EGT System s.r.o., Otice, Czech Republic).

- Dry mess min. 20%
- Combustible substances in dry matter min. 50%
- Sum of free amino acids min. 12%

Statistical analysis

The experimental results were analyzed by TIBCO Statistica®, Version 14.0 (TIBCO Software Inc., Palo Alto, California, USA). A multifactor analysis of variance (ANOVA) was used to determine the influence of the main factors and their interactions on the observed parameters. A post-hoc analysis (LSD Tukey test) with a significance level of α = 0.05 was used to determine the differences between the factors. Graphic results were created in the Microsoft Excel program (ver. 16.51).

Table 2. Application of stimulating substances

	Preparation	Applied dose	Growth phase
1	Control	Without the application of substance	
2	Humix Univerzál and Humix Bór	5+2 l/ha	BBCH 12 – 16 (3 – 6 leaves unfolded)
	Humix Univerzál and Humix Bór	5+2 l/ha	BBCH 16 – 19 (6 – 10 leaves unfolded)
	Humix Univerzál and Humix Bór	5+2 l/ha	BBCH 33 (30% cover of ground)
	Humix Univerzál	5 l/ha	BBCH 39 (full cover of ground)
3	ENERGEN Cleanstorm	0.7 l/ha	BBCH 12 – 16 (3 – 6 leaves unfolded)
	ENERGEN Cleanstorm	0.7 l/ha	BBCH 16 – 19 (6 – 10 leaves unfolded)
	ENERGEN Cleanstorm	0.7 l/ha	BBCH 33 (30% cover of ground)
	ENERGEN Cleanstorm	0.7 l/ha	BBCH 39 (full cover of ground)

RESULTS AND DISCUSSION

Root yield of sugar beet

The formation process of quantitative parameters is correlated with the environmental conditions and genetic variability of the cultivated variety (Ernst et al., 2023). The final yield is a result of the interaction of genotype and environment (G × E) (Al Jbawi et al., 2016). The analysis of the experimental results confirmed a statistically significant influence of year (P < 0.01) on the yield of sugar beet (Table 3). In 2021, the root yield was at the level of 68.99 t/ha (+9.68 t/ha; rel. 16.32%), while in 2022 a lower value was indicated at the level of 59.31 t/ha (Table 4).

Optimal beet production can be achieved by modifying the genetic potential and eliminating negative factors that limit the potential of root yield. Implication of resistant cultivars against diseases, and stress factors in accordance with good agronomic practices, modifies the production process of field crops (Fasahat et al., 2020). The selection of a suitable variety initializes the production potential of the crop in specific environmental conditions (Soltani and Soltani, 2015). Experimental statistical analysis confirmed the proven influence of selected sugar beet varieties (P < 0.01) on the formation of final yield (Table 3). In the range of monitored varieties, the average root yield was at the level of 64.15 t/ha. The highest yield was recorded by Darvas variety 65.83 t/ha (+1.68 t/ha; rel. 2.62%). In the case of the Okapi variety, the yield was indicated at the level of 63.95 t/ha (-0.21 t/ha; rel. 0.32%). The lowest yield was indicated by the Bukovina variety 62.68 t/ha (-1.47 t/ha; rel. 2.29%) (Table 4).

Table 3. Impact of main factors and their interactions on the observed parameters

	Root yield	Sugar content
	P – values	
Year	0.000**	0.000**
Variety	0.000**	0.001**
Treatment	0.000**	0.000**
Year*Variety	0.098	0.555
Year*Treatment	0.104	0.016*
Variety*Treatment	0.622	0.916
Year*Variety*Treatment	0.552	0.982

* Statistically significant effect by 0.95 confidence intervals
** Statistically significant effect by 0.99 confidence intervals

Table 4. Average values and significance inside factors at the 95% level (Tukey test)

Factor		Root yield (t/ha)	SD	Sugar content (%)	SD
Year	2021	68.99^{b}	±4.66	16.75^{b}	±0.44
	2022	59.31^{a}	±3.44	16.07^{a}	±0.28
Variety	Bukovina	62.68^{a}	±5.84	16.24^{a}	±0.55
	Okapi	63.95^{a}	±6.29	16.59^{b}	±0.47
	Darvas	65.83^{b}	±6.84	16.39^{ab}	±0.43
Treatment	Control	59.84^{a}	±4.79	16.11^{b}	±0.32
	Variant 1	65.22^{b}	±6.10	16.54^{a}	±0.57
	Variant 2	67.40^{c}	±5.79	16.58^{a}	±0.46

SD – standard deviation; Variant 1 – treatment with Humix Univerzál and Humix Bór; Variant 2 – treatment with ENERGEN Cleanstorm
Different small letters indicate significant differences (Tuckey HSD test, α = 0.05) between years, varieties, and treatments

The application of organic substances regulates biochemical processes, physiological aspects, the rate of photosynthesis and improves the efficiency of water use (Zhang et al., 2013), thereby stimulating the production process (Khodadadi et al., 2020). Biostimulants accelerate post-stress regeneration and reduce the consequences of oxidative stress. Experimental statistical analysis confirmed a significant effect of the variant (P < 0.01) on the yield of sugar beet (Table 3). On the control variant, the root yield was recorded at the level of 59.84 t/ha. The results of the statistical analysis confirmed the positive influence of stimulants on the production potential of sugar beet. On variant 1, the average yield was 65.22 t/ha (+5.38 t/ha; rel. 8.99%). In terms of the formation of quantitative indicators, a higher yield was indicated by variant 2 with a yield of 67.40 t/ha (+7.56 t/ha; 12.64%). Mutual interactions between factors year*variety; year*treatment and variety*treatment were statistically non-significant (P > 0.05) in terms of the formation of quantitative production parameters (Table 4).

The sugar content of sugar beet

Sugar content is considered the basic economic element of sugar beet evaluation (Bloch et al., 2016). Within the framework of the rationalization of the cultivation system, it is necessary to consider the variability of weather conditions, which have an impact on the formation of sugar content (Ernst et al., 2022). The experimental results confirmed the significant impact of year weather conditions (P < 0.01) on the sugar content formation (Table 3). In 2021, the sugar content was at the level of 16.75% (+0.68%; rel. 4.21%), compared to 2022, when the sugar content was at the level of 16.07% (Table 4).

The selection of suitable genotypes in variable agroecological conditions is an important intensification factor. Qualitative parameters are modified by the interaction of environment and genotype, which specifies physiological characteristics and modulates qualitative indicators (Moosavi et al., 2017). In the range of monitored production parameters, the statistically proven influence of the genotype (P < 0.01) on the formation of the final sugar content was confirmed (Table 3). In the range of monitored sugar beet varieties, the average sugar content was indicated at the level of 16.41%. The highest sugar content was indicated by Okapi at 16.59% (+0.18%; rel. 1.11%), followed by Darvas with a sugar content at the level of 16.39% (-0.02%; rel. 0.10%). The lowest sugar content was monitored by the Bukovina variety 16.24% (-0.17%; rel. 1.01%) (Table 4).

The foliar application of stimulating substances and adaptogens affects the formation of saccharose and reduces the content of molasses-forming elements in sugar beet root (Alotaibi et al., 2021). Humic compounds influence physiological aspects and the formation of qualitative parameters (Thalooth et al., 2019). Statistical analysis confirmed the significant influence of the variant (*P* < 0.01) on the formation of sugar content. The interaction effect of the factors, year*variety and variety*treatment was statistically non-significant (*P* > 0.05). Interaction of year*treatment was statistically significant (*P* < 0.05) (Table 3). Stimulating preparations had a positive influence on the formation of sugar content. The average sugar content of the control variant was at the level of 16.11%. By variant 1, the sugar content was at the level of 16.54% (+0.42%; rel. 2.62%) and the highest sugar content was recorded by variant 2, where the sugar content was at the level of 16.58% (+0.47%; rel. 2.91%) (Table 4).

CONCLUSION

The field polyfactorial experiment with sugar beet was carried out on a research-experimental basis in 2021 – 2022. The trial was aimed at monitoring agroecological conditions, selected genotypes, stimulating substances and adaptogens. The results of the experiment declare a statistically proven influence of the environmental factors (*P* < 0.01), selected genotypes (*P* < 0.01) and applied substances (*P* < 0.01) on the formation of quantitative and qualitative parameters. Agroecologically more favourable conditions were recorded in 2021 when a higher root yield of 68.99 t/ha (+9.68 t/ha) and sugar content of 16.75% (+0.68%) was indicated. The highest root yield was shown by the Darvas variety at 65.83 t/ha (+1.68 t/ha; rel. 2.62%), and the highest sugar content by the Okapi variety at 16.59% (+0.18%). Foliar application of stimulating substances and adaptogens positively influenced the quantitative and qualitative production indicators during two meteorologically different years. The application on variant 2 was more effective, where the root yield was indicated at the level of 67.40 t/ha (+7.56 t/ha; rel. 12.64%) and sugar content was 16.58% (+0.47%). Foliar application of stimulants and adaptogens can be considered as an important rationalization tool of sugar beet cultivation technology.

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