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VARIABILITY OF SEASONAL CONDITIONS AND HYBRID INFLUENCE ON SUNFLOWER (*HELIANTHUS ANNUS* L.) PRODUCTIVITY AND OIL CONTENT

Ivan Ravza[1], Ivan Černý[1], Tomáš Vician[1], Dávid Ernst[1], Alexandra Zapletalová[2]

[1] Institute of Crop Production, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic

[2] Institute of Agrochemistry and Soil Sciences, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic

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Abstract

This study examines the influence of seasonal conditions and hybrid selection on the yield-forming parameters, seed yield, and oil content of sunflower (*Helianthus annuus* L.). The research was carried out as a field experiment on the plots of AGRO SAP s.r.o., located in the village of Nenince, Slovakia. Four sunflower hybrids (ES Poetic, ES Electric, SY Talento, Marbelia CS) were selected to monitor the variability of the selected parameters during the growing seasons 2020–2022. The statistical analysis of the collected data confirmed a highly significant effect of the studied factors on productive traits of sunflower. Over the study period, the average yield of sunflower was 3.48 tonnes per hectare (t/ha), with an average oil content of 38.92%. Among the climatic factors analyzed, precipitation distribution had the greatest influence on oil content, while temperature fluctuations were the key factor affecting seed yield. The seasonal conditions of 2020 was the most favorable for yield-forming parameters, recording the highest head diameter (176.6 ± 0.82 mm), head weight (182.83 ± 8.46 g), and thousand seed weight (TSW) (64.58 ± 2.23 g). However, 2021 provided optimal conditions for seed yield (3.79 ± 0.24 t/ha) and oil content (40.51 ± 0.51%). Among the hybrids, Marbelia CS excelled in yield-forming traits by head diameter (168.5 ± 1.51 mm), TSW (64.33 ± 2.34 g), while ES Poetic showed the highest seed yield (3.69 ± 0.36 t/ha) and ES Electric recorded the highest oil content (39.43 ± 1.15%). These findings highlight the importance of seasonal climatic conditions and hybrid selection in sunflower cultivation, providing essential insights for optimizing yield and oil production.

Keywords: sunflower, hybrids, production, yield formating factors, seed yield, oil content

INTRODUCTION

Oilseed crops hold significant importance from economic, social and environment perspectives. They serve as essential sources of food, animal feed and raw materials for various industrial processes. Additionally, these crops are widely regarded for their environmentally sustainable characteristics, contributing to eco-friendly agricultural practices (Popescu, 2020). Approximately 40 oilseed species produce consumable oils, yet only a few contribute significantly to global trade and the overall supply of oilseeds. Oil crops are cultivated worldwide under diverse agro-climatic conditions, serving as crucial commodities in the trade and economy of numerous nations (Kaya *et al.*, 2012).

Sunflower (*Helianthus annuus* L.), an annual species native to Central and North America is believed to have been domesticated by indigenous peoples over 3 000 years ago. They utilized the plant for its nutritional and medicinal properties as well as for ceremonial purposes such as body paint (Kaya *et al.*, 2012; Krsmanović *et al.*, 2020). Currently, sunflower is cultivated in the whole world, and through scientific advancements and long-term research, it has become widely applied in diverse sectors. It serves as a source of food and medicine, animal feed, ornamental plant and industrial raw material (Krsmanović *et al.*, 2020).

Globally, sunflower is cultivated on approximately 29.3 million hectares, with a production of 54.2 million tons and an average yield of 2.03 t/ha (Faostat, 2022). In terms of global production, sunflower ranks among the top five oil crops, alongside soybeans and rapeseed (Babec *et al.*, 2020). Russia, Ukraine, European Union, and Argentina are the leading producers of sunflower with a 70% share of the global market (Singh *et al.*, 2022).

Sunflower is primarily cultivated for both edible oil and confectionary seeds, serving human consumption (e.g. salad oil, frying oil, ready meals) and livestock consumption (Debaeke and Izquierdo, 2021). Additionally, sunflower finds application in the chemical industry (soap production, glycerin, paints and varnishes) and the pharmaceutical industry (pills and cosmetic products). It is also utilized in biodiesel production, bee pasture, and as an ornamental plant (Markulj *et al.*, 2014).

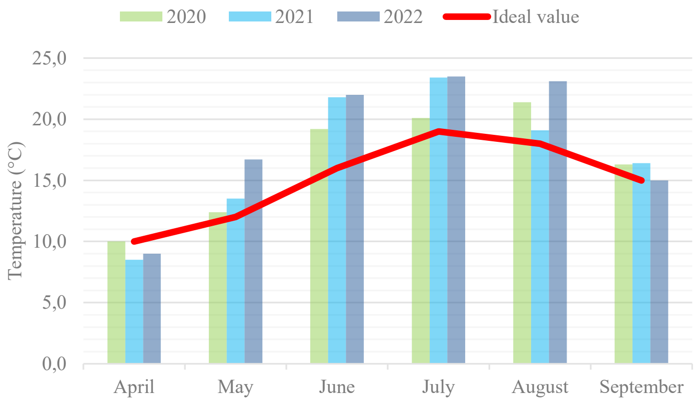
The primary objective in sunflower cultivation is to achieve high seed and oil yields (Balić *et al.*, 2019). Sunflower production is influenced by a multifaceted interplay of growth, physiological and biochemical processes that together influence the development of quantitative and qualitative yield traits (Johnston *et al.*, 2002). This complex interaction is significantly modulated by the hybrid variety and its response to environmental conditions, which together regulate the duration of growth stages and the formation of yield components. To optimize these factors, high-yielding hybrids should be cultivated, with appropriate agronomic practices (Kolomaznik *et al.*, 2012). The selection of the correct hybrid is critical for achieving consistent production and high-quality yields, as the hybrid serves as an autonomous genetic, biological, and agronomic determinant influencing both quantitative and qualitative production levels (Živanović *et al.*, 2017).

Since seed yield and oil content are the most critical components of sunflower production, monitoring their variability under different cultivation factors is essential. Among the key factors influencing sunflower productivity, seasonal weather conditions and hybrid variability play a significant role. This study aims to assess the extent to which these factors impact the yield performance of sunflower, providing insights into their influence on production outcomes.

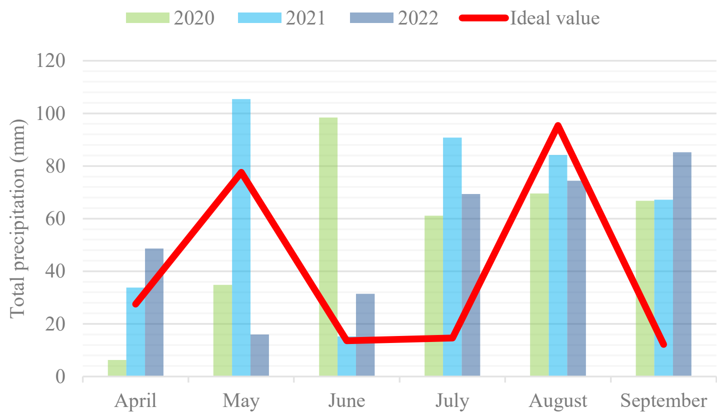
MATERIALS AND METHODS

Experimental Location

The experiment was carried out in 2020–2022 in the field conditions of AGRO SAP s.r.o., located in the village of Nenince, Slovakia (48°8’34.17” N and 19°16’7.20” E). This company manages an area of 1 346 ha, including 1 190 ha of arable land in the cadastral areas of Nenince, Bátorová, Opatovská Nová Ves and Príbelce. The village of Nenice, where the experiment was established, is located in a maize production area, it has a slope profile with an altitude of 190 m above sea level. This region is characterized by a warm, moderately dry climate with mild to cold winters. The average annual temperature is 9.4 °C. The highest values of precipitation occur most often during summer storms, in the months of July and August, otherwise the observed area is characterized by a low amount of precipitation. The average annual precipitation is 631 mm. Rainfall and average temperature data for the growing seasons during the experimental years were recorded by a hydrometeorological station



1: *Temperature conditions (°C) during the experimental season compared to ideal requirement of sunflower*



2: *Total precipitation (mm) during the experimental season compared to ideal requirement of sunflower*

situated directly at the experimental site. Fig. 1 and Fig. 2 illustrate the weather characteristics during the growing seasons 2020–2022 compared to the ideal requirements for sunflower growth according to Zapletalová *et al.* (2024).

Experimental Material

Four hybrids of sunflower were selected in terms of quantitative and qualitative parameters of final production formation. Hybrids Marbelia CS (Saatbau, Linz, Austria), SY Talento (Syngenta Group, Basel, Switzerland) intended for Clearfield technology and hybrids ES Poetic and ES Electric (Lidea, France) intended for Clearfield Plus technology were monitored. Clearfield and Clearfield Plus sunflower hybrids possess natural resistance to imidazolinone (IMI) herbicides, designed for postemergent weed control. This herbicide tolerance trait, derived from wild populations of *Helianthus annuus*, classifies these hybrids as non-genetically modified (Vician *et al.*, 2022). Both technologies aim to enhance the efficiency and sustainability of sunflower production by providing effective weed management, with Clearfield Plus hybrids offering superior IMI tolerance, enabling the use of higher herbicide rates, improved weed control, increased crop safety, and potentially higher yields.

The Marbelia CS hybrid is characterized by rapid initial growth and high yield potential. It is a medium-early hybrid with intermediate flowering and maturation. Marbelia CS is characterized by high plasticity, resistance to pathogens such as *Sclerotinia sclerotiorum*, *Plasmopara halstedii*, *Phomopsis helianthi*, *Verticillium*, and *Phoma*. The plant develops a medium-height habitus with a semi-drooping, convex, and medium-sized flower head.

Hybrid SY Talento is a medium-early high oleic sunflower hybrid with rapid initial development. The plants reach medium height (130–180 cm) and have robust stems. This hybrid is characterized by early flowering and maturation. It has semi-drooping, uniform flower heads. The seed contain a high oil content (48.5%). It excels in tolerance to stem and flower head infections *Sclerotinia*, and it is also tolerant to *Puccinia helianthi* and resistant to all known species of *Peronospora*.

ES Poetic is a medium-early hybrid with a high oil content in the seeds. It demonstrates moderate initial growth and an intermediate maturation period. The plants are medium-tall and resistant to lodging, with moderate resistance to diseases.

ES Electric is a medium-early hybrid with high yield potential, notable for its superior herbicide tolerance, exhibiting low phytotoxicity. It shows moderate initial growth and excellent health due to its exceptional tolerance to three major diseases: *Sclerotinia, Puccinia helianthi,* and *Verticillium*.

Experimental Methods

Field polyfactorial experiments were set up using the method of vertically split blocks, with random arrangement of experimental members. In the crop rotation system the pre-crop was winter wheat (*Triticum aestivum* L.). The soil preparation and establishment of the crop was carried out using conventional technology with sowing at a distance of 0.75 m between rows. Weed control or protection against diseases and pests was carried out according to their occurrence and according to the current Methodological Manual of Plant Protection. Basic fertilization was conducted based on agrochemical soil analysis. Soil samples were collected in line with the methodological guidelines of the Central Institute of Agricultural Inspection and Testing (ÚKSÚP, 2022) during both autumn and spring, with an expected sunflower yield of 3.0 t/ha. Industrial fertilizers were applied at the following rates: NPK 10-24-24 (100 kg/ha) and urea (46%) (300 kg/ha). The application rate was determined using the balance method, considering the existing nutrient content in the soil and the efficiency of nutrient absorption from both soil and fertilizers. The determination methods for individual nutrients and results are listed in Tab. I. The number of plants and head number per unit area were determined during the preharvest inventory, while other yield

I: *Spring and autumn analysis of soil samples on the experimental area in 2020–2022*

Autumn			
Nutrient and determination method	2020	2021	2022
Phosphorus (mg/kg) – colorimetrically by Mehlich III	18.80	72.00	58.00
Potassium (mg/kg) – flame photometry by Mehlich III	235.00	213.40	225.00
Magnesium (mg/kg) – AAS by Mehlich III	706.10	477.00	531.00
Calcium (mg/kg) – AAS by Mehlich III	4 200.00	3 980.00	4 050.00
Zinc (mg/kg) – AAS by Mehlich III	1.21	1.46	1.38
Manganese (mg/kg) – AAS by Mehlich III	4.53	4.28	4.41
pH – by KCl (0.2 mol/dm^3 KCl) (pH units)	6.69	6.60	6.65
Humus (%) – calculated based on Tjurin's method	2.63	2.18	2.43
Spring			
Nutrient and determination method	2020	2021	2022
IN (mg/kg) – sum of ammonium and nitrate nitrogen	12.55	6.60	8.65
NO_3^- – N (mg/kg) – colorimetrically by phenol 2,4-disulfonic acid	5.80	2.50	3.85
NH_4^+ – N (mg/kg) – colorimetrically by Nessler's reagent	6.75	4.10	4.80

IN – inorganic nitrogen; AAS – atomic absorption spectrophotometer

formating parameters like head diameter (cm), weight of individual heads (g) and TSW (g) were analysed by mechanical analysis in the laboratory of the Institute of Crop Production, Slovak University of Agriculture in Nitra according to Zapletalová *et al.* (2024). Yield was determined through yield-forming elements according to the methodology of Ernst *et al.* (2016). The oil content of sunflower seed samples (sample weight 200 g) was determined by the extraction method (%) using Soxhlet extraction apparatus according to Shahidi (2005).

Statistical Analysis

The results obtained from the experiment were evaluated using TIBCO Statistica® statistical software, Version 14.0 (TIBCO Software Inc., Palo Alto, California, USA). The effects of the experimental factors on the observed sunflower parameters were assessed through multivariate analysis of variance (ANOVA). Post-hoc comparisons were conducted using Tukey's HSD test to identify significant differences between factors, with a significance level set at $\alpha = 0.01$. Microsoft Excel (Version 16.51) was employed for graphical representation of the results.

RESULTS AND DISCUSSION

Yield-forming Parameters

Climate change, characterized by temperature fluctuations and uneven rainfall distribution during the main vegetation period of the sunflower, significantly affects the quantity and quality of the crop's production (Ernst and Černý, 2018). These factors crucially influence the physiological processes of plants, such as germination, biomass accumulation, flowering, and the formation of heads and seeds, directly determining the final yield.

The claim that weather conditions during the growing season significantly affect sunflower production is supported by several studies. Amjed *et al.* (2011); Rauf *et al.* (2012) and Balalić *et al.* (2016) reported the effect of seasonal weather conditions on the variables head diameter, weight of head, and TSW was found to be highly statistically significant, which is partially comparative with the results of our experiments. We confirmed a statistically significant ($p \leq 0.05$) influence of the seasonal conditions on head diameter and a statistically highly significant effect ($p \leq 0.01$) on head weight (Tab. II). Conversely, the influence of the seasonal conditions on the TSW was statistically non-significant.

Based on our findings, the most favorable weather conditions for yield-forming parameters during the monitored period was 2020. In these seasonal conditions, the highest values of head diameter (176.6 ± 0.82 mm), head weight (182.83 ± 8.46 g), and TSW (64.58 ± 2.23 g) were recorded. On the other hand, the weather conditions of the year 2022 were least favorable for the parameters of head diameter (147.0 ± 0.32 mm) and weight of head (148.75 ± 3.09 g), while the lowest TSW (62.33 ± 1.61 g) was measured in the year 2021 (Tab. II).

The impact of weather conditions during the sunflower main vegetation period can be mitigated by selecting appropriate genetic material. Hybrid Marbelia CS achieving the best results across the monitored parameters. This hybrid exhibited the largest head diameter (168.5 ± 1.51 mm), the highest head weight (171.33 ± 18.46 g), and the greatest TSW (64.33 ± 2.34 g). In contrast, the hybrid SY Talento showed the lowest values for head diameter

(164.1 ± 1.58 mm) and TSW (61.89 ± 1.05 g), while the hybrid ES Electric recorded the lowest head weight (162.00 ± 13.18 g) (Tab. III).

Analysis of variance revealed a statistically highly significant effect of genetic material on head diameter (Tab. II), which is in agreement with the findings of Veverková and Černý (2012) and Balalić *et al.* (2016). Authors Rondanini *et al.* (2003); Gholinezhad *et al.* (2009); Černý and Mátyás (2012) and Andrianasolo *et al.* (2016) found a statistically significant effect of hybrids on the weight of head and TSW. However, the findings of these authors regarding the above parameters contradict the results of the present study, as the effect of hybrids on these parameters was evaluated as statistically insignificant (Tab. II).

These results emphasize the importance of combining appropriate genetic material with optimum growing conditions to achieve maximum yield.

Yield of Seed

In crop production, yield is considered the most important socioeconomic category (Jocković *et al.*, 2019). Seed yield is a complex quantitative trait that is determined by many traits that are mostly polygenic in nature and are strongly influenced by environmental factors (Baraiya *et al.*, 2018).

According to Balalić *et al.* (2019), there are significant differences in seed yield between hybrids, growing years, and locations where sunflower is cultivated. This phenomenon was also demonstrated within our research where statistically highly significant effect of the year ($p \leq 0.01$) on the average yield of sunflower seeds over a three-year period was observed (Tab. II). The highest seed yield was obtained in 2021 at the level of 3.79 ± 0.24 t/ha (Tab. III).

Based on the findings, it can be concluded that the weather conditions during the 2021 growing season were more favorable for sunflower cultivation. This is reflected in the higher average yield obtained in comparison to other seasons, indicating that the environmental factors during this period were more conducive to optimal sunflower growth and productivity.

Another important factor for sunflower cultivation is the choice of biological material, which significantly influences the yield potential. Four hybrids with similar yield property were included in our experiment.

During the monitored experimental period, the highest average yield was recorded by the hybrid ES Poetic, 3.69 ± 0.36 t/ha, closely followed by the hybrid ES Marbelia with an average yield of 3.66 ± 0.43 t/ha. The lowest value of seed yield was recorded by the hybrid ES Talento 3.17 ± 0.70 t/ha (Tab. III). This finding confirmed that the selection of hybrids has a highly statistically significant effect on sunflower seed yield. A graphical representation is provided in Fig. 3, clearly illustrating the differences in average yield among the selected hybrids during the study period. Similar findings were reported by Vician *et al.* (2022), who observed a significant influence of both the growing season and biological material on sunflower yield. Balalić *et al.* (2012) also noted that, in addition to hybrid selection, location played a crucial role in yield variability. They attributed this to the interaction between hybrids and environmental factors, which can lead to substantial variation in traits and yield potential. For this reason, it can be said that the selection of hybrids suited to the agro-ecological conditions of the selected location is important in cultivation.

Oil Content

Oil content is a trait primarily determined by the genetic potential of a given hybrid but is significantly influenced by environmental factors and their interaction (Balalić *et al.*, 2012). According to Škorić (2012) the most impactful environmental factors affecting the oil content include average daily air temperatures and soil moisture levels. In dry years, oil content tends to be lower than in wetter years, particularly when moisture deficit occur during the flowering-ripening period (Balalić *et al.*, 2012). The weather conditions of the years 2020–2022 had a statistically high significant effect ($p \leq 0.01$) on the oil content of sunflower seeds. Similar to yield, the seasonal conditions of 2021 showed the highest average oil content at 40.51 ± 0.51% (Tab. III). Ernst *et al.* (2024) confirmed that vintage significantly affects oil content as did Škorić and Marinković

II: *Analysis of variance (ANOVA) for the monitored years 2020–2022*

Effect	Monitored parameter				
	Head diameter (mm)	Weight of head (g)	TSW (g)	Yield (t/ha)	Oil content (%)
	P-values				
Year	0.012943*	0.007440**	0.506901	0.000000**	0.000000**
Hybrid	0.196036	0.004691**	0.972819	0.000000**	0.000000**
Year*Hybrid	0.736374	0.055637	0.043330	0.000010**	0.000000**

*statistically significant effect by 0.95 confidence intervals; **statistically significant effect by 0.99 confidence intervals; TSW – thousand seed weight

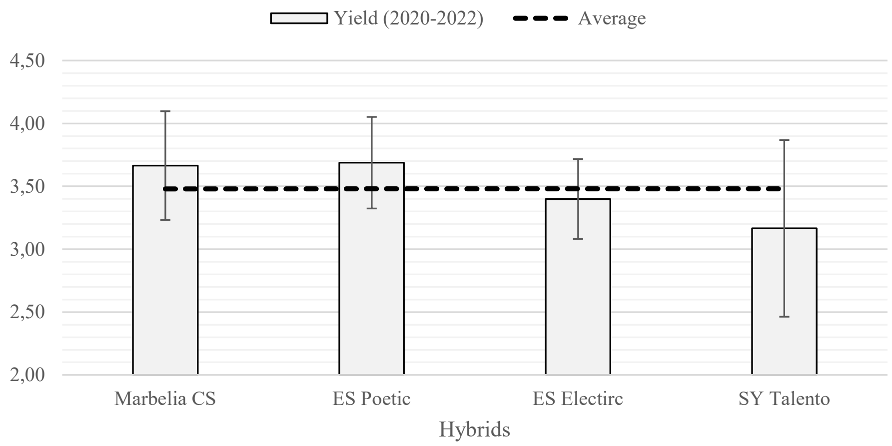
(1990), who observed high variability in oil content depending on the cultivation year.

In addition to environmental factors, genetic diversity among hybrids also plays a significant role in oil content as shown a contribution of Černý *et al.* (2018). Our experiment supports this, with hybrid variation showing a statistically highly significant effect ($p \leq 0.01$) on oil content. The average oil

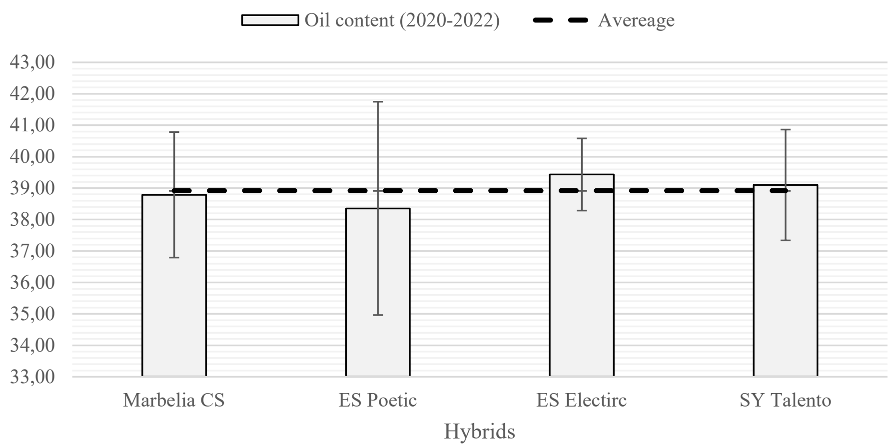
III: *The average of the values within the monitored factors and significance of their differences at the level of 99% (Tukey test)*

Factor	Statistical element	Head diameter (mm)	Weight of head (g)	TSW (g)	Yield (t/ha)	Oil content (%)
Year	2020	176.6 ± 0.82a	182.83 ± 8.46c	64.58 ± 2.23b	3.40 ± 0.76a	36.19 ± 1.56a
	2021	174.7 ± 0.52a	169.67 ± 11.87b	62.33 ± 1.61a	3.79 ± 0.24b	40.51 ± 0.51c
	2022	147.0 ± 0.32b	148.75 ± 3.09a	62.67 ± 1.61a	3.25 ± 0.08a	40.06 ± 0.16b
Hybrid	Marbelia CS	168.5 ± 1.51a	171.33 ± 18.46a	64.33 ± 2.34c	3.66 ± 0.43b	38.79 ± 2.00a
	ES Poetic	167.2 ± 1.69a	169.89 ± 19.11a	64.22 ± 1.72bc	3.69 ± 0.36b	38.36 ± 3.39c
	ES Electric	164.5 ± 1.38a	162.00 ± 13.18a	62.33 ± 1.87ab	3.40 ± 0.32a	39.43 ± 1.15b
	SY Talento	164.1 ± 1.58a	165.11 ± 15.79a	61.89 ± 1.05a	3.17 ± 0.70a	39.10 ± 1.76ab

different letters indicate significant differences (Tukey HSD test, α = 0.05) between growing seasons and hybrids



3: *Sunflower seed yield (t/ha)*
The dashed line indicates the average value of genotypes for the whole statistical set. Error bars represent standard deviation (SD)



4: *Sunflower oil content (%)*
The dashed line indicates the average value of the varieties for the whole statistical set. Error bars represent standard deviation (SD)

content across the selected hybrids was 38.92% during the study period (Fig. 4). Among the selected hybrids, ES Electric exhibited the highest oil content (39.43 ± 1.15%) while ES Poetic had the lowest oil content (38.36 ± 3.39%) (Tab. III). These results align with previous findings, where significant differences in oil content were observed between genotypes (Miklič *et al.*, 2014; Mijić *et al.*, 2017; Khan *et al.*, 2018).

CONCLUSION

Based on the results obtained from the field experiment, it was determined that seasonal conditions during the studied period 2020–2022 had a statistically significant impact ($p \leq 0.05$) on sunflower yield parameters, seed yield, and oil content. Climatic factors, such as temperature and rainfall variations during the growing season, played a key role in determining sunflower productivity.

Among the evaluated seasons, 2020 was identified as the most favorable in terms of yield parameters, recording the highest head diameter (176.6 ± 0.82 mm), head weight (182.83 ± 8.46 g), and TSW (64.58 ± 2.23 g). In contrast, the conditions in 2021 proved to be the most favorable for total seed yield and oil content, with an average seed yield of 3.79 ± 0.24 t/ha and an average oil content of 40.51 ± 0.51%. Conversely, the lowest yield was observed in 2022 (3.25 ± 0.08 t/ha) and the lowest oil content was recorded in 2020 (36.19 ± 1.56%).

Regarding hybrid performance, the Marbelia CS hybrid showed the best results in terms of yield parameters, including the largest head diameter (168.5 ± 1.51 mm), head weight (182.83 ± 8.46 g) and TSW (64.33 ± 2.34 g). Meanwhile, ES Poetic achieved the highest seed yield (3.69 ± 0.36 t/ha), while ES Electric recorded the highest oil content (39.43 ± 1.15%). The hybrid SY Talento showed the lowest seed yield (3.17 ± 0.70 t/ha) and TSW (61.89 ± 1.05 g).

These findings underscore the significant influence of climatic factors and hybrid selection on sunflower productivity. The results indicated that 2020 was optimal for the development of yield-forming parameters, 2021 provided the most favorable conditions for high seed yield and oil content. These findings underscore the importance of hybrid selection and the consideration of climatic variability in sunflower cultivation. By integrating these factors, producers can effectively optimize both yield and oil quality under changing climate conditions.

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Contact information

Ivan Ravza: xravza@uniag.sk
Ivan Černý: ivan.cerny@uniag.sk
Tomáš Vician: tomas.vician@uniag.sk (corresponding author)
Dávid Ernst: david.ernst@uniag.sk
Alexandra Zapletalová: alexandra.zapletalova@uniag.sk