Physiological and Biochemical Responses of Sunflower Hybrids Under Field Conditions

Fiziološki i biokemijski odgovori hibrida suncokreta u poljskim uvjetima

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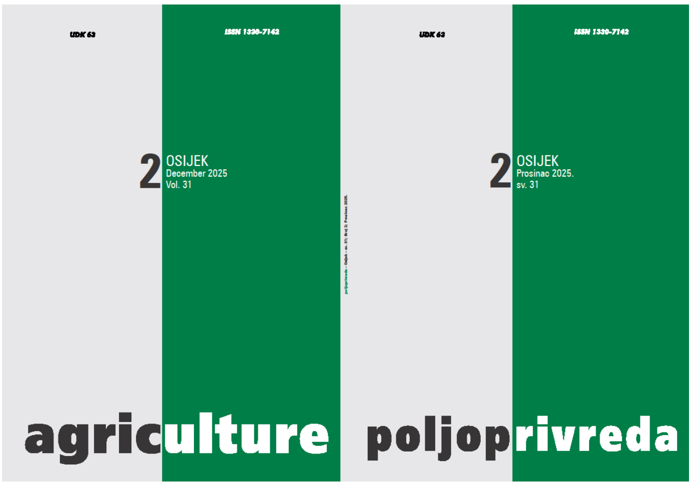

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PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF SUNFLOWER HYBRIDS UNDER FIELD CONDITIONS

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SUMMARY

This study investigated the physiological and biochemical responses of three sunflower (Helianthus annuus L.) hybrids (Luka, Matej, and OS-H-17) under field conditions in 2021 and 2022. According to the analysed data, significant year variability was observed. In 2021, higher ambient and leaf temperatures, as well as higher radiation, led to reduced performance index (PI_{ABS}) and increased phenolic accumulation. In 2022, slightly cooler conditions with lower radiation favoured higher chlorophyll content, PI_{ABS}, and higher catalase and ascorbate peroxidase activities. Principal component analysis separated years and differentiated hybrids according to their response strategies. Luka was associated with chlorophyll stability and enzymatic antioxidants, while Matej and OS-H-17 relied more on non-enzymatic mechanisms. Therefore, variations in the environment have a significant effect on the physiology and biochemical responses of sunflowers. Hybrids have exhibited specific characteristics related to adaptive mechanisms. Luka showed the most stable antioxidant and photosynthetic performance, highlighting the importance of hybrid selection in producing climate-resistant sunflowers.

***Keywords:** F_V/F_M, PI_{ABS}, antioxidant activity, photosynthetic pigment, year*

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is a major oilseed crop grown worldwide for its edible oil, but it is also a valuable component of crop rotation. In Croatia, 59900 ha of arable land were recorded under sunflower cultivation in 2023, with a yield of 2.63 t/ha (FAOstat, 2025). Its productivity and oil quality are strongly influenced by environmental conditions, such as temperature, radiation, and water availability, which are becoming increasingly variable due to the influence of climate change. These abiotic stresses often impair photosynthetic performance and induce oxidative stress, thereby reducing plant growth and yield. Understanding the physiological and biochemical basis of sunflower stress responses is therefore crucial for breeding and management aimed at improving resilience (Jocković et al., 2024).

The process that sustains plant growth and productivity by converting light energy into chemical energy is called photosynthesis. The efficiency of photosynthesis in each individual plant. It affects biomass accumulation and crop yield. It is also highly dependent on environmental conditions. Therefore, assessing the functionality of the photosynthetic apparatus is crucial for understanding plant performance under changing conditions. Chlorophyll *a* fluorescence and derived JIP parameters provide a rapid, nondestructive indication of photosystem II (PSII) functionality and whole-plant photosynthetic efficiency. The JIP framework links changes in fluorescence to specific biophysical steps in energy absorption, electron capture, and transport. The photosynthetic performance index (PI_{ABS}) specifically integrates changes in several functional components of PSII, making it a sensitive indicator of the decline in photochemical efficiency caused by changes in the environment (Strasser et al., 2004). These tools have been widely applied in sunflower research to screen genotypes and quantify the effects of drought, heat and high radiation on the photosynthetic mechanism (Çiçek et al., 2019; Markulj Kulundžić et al., 2023). In parallel, biochemical indicators, particularly total phenolic content (TPC), DPPH radical scavenging activity,

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and enzymatic antioxidants such as catalase (CAT) and ascorbate peroxidase (APX), show how plants manage reactive oxygen species (ROS) under adverse conditions. Sunflower tissues (seeds and leaves) are known to contain high levels of phenolic acids (e.g., chlorogenic acids) and tocopherols, which contribute significantly to their antioxidant capacity. Changes in antioxidant enzyme activity often reflect inducible stress-responsive defences. The balance between enzymatic and non-enzymatic antioxidants may differ among genotypes and developmental stages, affecting overall tolerance (Adeleke and Babalola 2020; Abdalla et al., 2021).

A key unresolved question in sunflower physiology is the relative contribution of genotype (G), environment (E), and their interaction (G × E) to photosynthetic performance and antioxidant properties. Some field and controlled environment studies report strong genetic control of traits, such as DPPH scavenging or specific fluorescence parameters, suggesting stable, heritable differences that are amenable to selection. Other papers document significant environmental or seasonal influences, for example, changes in pigment content that alter irradiance and temperature, PI_{ABS} and phenolic accumulation, and important G × E interactions that complicate selection in breeding programs. Therefore, evaluation of hybrids in contrasting seasons and environments is necessary to identify reliably tolerant genotypes (Chen et al., 2023).

Based on these approaches, this study aims to investigate the early physiological and biochemical responses of three genetically distinct sunflower hybrids under two years of field trials and to identify the most stable hybrid.

MATERIAL AND METHODS

The experiments were conducted in 2021 and 2022 at the Agricultural Institute Osijek, Croatia (45°32′N, 18°40′E). Three sunflower hybrids were included in the experiment: Luka, Matej, and OS-H-17 (Agricultural Institute Osijek). The experiment was set up in a randomised complete block design (RCBD) with three replications, using a plot size of 20 m^2 (5 × 4 m), row spacing of 70 cm, and a plant spacing within the row of 25 cm. The experimental soil was a eutric Cambisol with good physical and chemical properties. It was characterised by a pH in KCl of 6.25, a humus content of 2-2.2%, a K_2O concentration of 37.7 mg/100 g soil and a P_2O_5 concentration of 39.7 mg/100 g soil. Agrotechnical measures (fertilisation, plant protection) were carried out according to local recommendations. Sowing was carried out in April, and harvesting in September each year. According to the Croatian Meteorological and Hydrological Service (fig. 1), during the sunflower growing season (April–September), air temperatures during both study years (2021 and 2022) were slightly above the long-term average (2003–2023). The differences are particularly noticeable from June to August. Precipitation varied significantly between years. In 2022, lower precipitation was recorded in May and June and higher precipitation in September. These deviations indicate warmer and drier conditions during key growth phases compared to the long-term climate pattern. The mean ambient temperatures and photosynthetic photon flux densities (PPFD) during physiological measurements on 8 June 2021 were 22.6 °C and 823 μmol m^{-2} s^{-1}, respectively, and on 2 June 2022, they were 22.3 °C and 792 μmol m^{-2} s^{-1}.

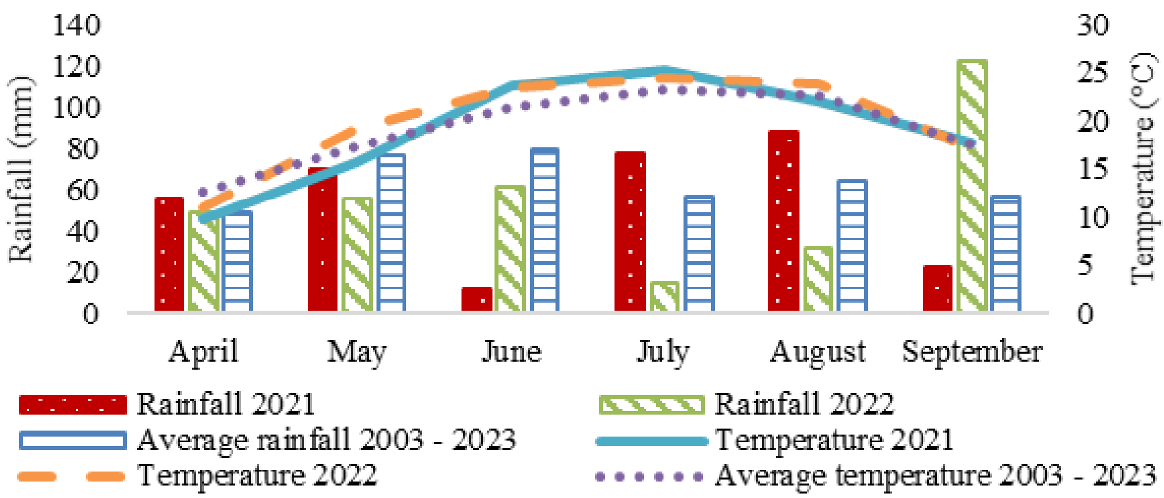

Figure 1. The mean monthly air temperatures (°C) and total monthly rainfall (mm) during the 2021 and 2022 growing seasons, and a long-term (2003-2023) average rainfall and temperature in Osijek.

Grafikon 1. Srednje mjesečne temperature zraka (°C) i ukupne mjesečne oborine (mm) tijekom vegetacijskih sezona 2021. i 2022. te dugoročni (2003. - 2023.) prosjek oborina i temperature u Osijeku.

Physiological measurements: The chlorophyll *a* fluorescence parameters, maximum quantum efficiency of photosystem II (F_V/F_M), and performance index (PI_{ABS}) (Strasser et al., 2004) were determined using a Handy PEA (Hansatech, UK) on dark-adapted leaves for 30 min, as previously established by Markulj Kulundžić et al. (2024). Leaf temperature was measured using an infrared thermometer (B+B Thermo-Technik GmbH, Germany) on the same leaves on which the clip for chlorophyll fluorescence measurement was placed. Physiological measurements were taken on 18 plants (6 × 3 repetitions) in the morning hours, from 7:30 to 8:30, during the vegetation developmental stage of sunflower (V5/V6 according to Schneiter et al., 2019).

Biochemical analysis: Immediately after the physiological measurements, the same leaves were sampled for determination of total phenolics according to Folin-Ciocalteu method (Singleton and Rossi, 1965), antioxidant activity by DPPH (2,2-diphenyl-1-picrylhydrazyl) free radicals (Brand-Williams et al., 1995), photosynthetic pigments - total chlorophyll and carotenoids (Lichtenthaler, 1987), enzymes: catalase - CAT (Aebi, 1984) and ascorbate peroxidase - APX (Nakano and Asada, 1981), and dry matter (DW, drying at 70 °C to constant mass).

Statistics: A two-way ANOVA (factors: genotype and year) was used to test differences between mean values, with Tukey HSD *post-hoc* tests ($p < 0.05$). The figures show mean values with standard deviations (F_V/F_M and PI_{ABS} - $n = 6$; phenolic and DPPH - $n = 5$; enzymes and pigments - $n = 5$). Multivariate analysis was performed using PCA. All physiological and biochemical parameters were included in the PCA. The *Statistica* program (ver. 14, TIBCO Software Inc., Palo Alto, CA, USA) was used to perform statistical analyses.

RESULTS AND DISCUSSION

Analysis of Variance

Analysis of variance (ANOVA) revealed significant effects of hybrid, year and their interaction on most traits (Table 1). In F_V/F_M, the year was not significant, unlike PI_{ABS}, where all sources of variability were significant. This establishes differences between hybrids and seasons, confirming the influence of both genetic background and environment on photosynthetic efficiency. Biochemical traits showed variable responses. Phenolics were stable among hybrids, while DPPH and CAT reflected hybrid and environment-specific antioxidant activity. APX was mainly influenced by the year. All factors strongly influenced photosynthetic pigment traits (total chlorophyll and carotenoids).

Table 1. Analysis of variance (F and p values) for photosynthetic efficiency parameters (F_V/F_M, PI_{ABS}), antioxidant parameters (phenolics, DPPH, catalase - CAT, ascorbate peroxidase - APX), pigment content (total chlorophyll - Chl, carotenoids - Car), and leaf temperature (LT) of sunflower hybrids across two growing seasons (2021 and 2022).

Tablica 1. Analiza varijance (F i p vrijednosti) za parametre fotosintetske učinkovitosti (F_V/F_M, PI_{ABS}), antioksidativne parametre (polifenoli, DPPH, katalaza - CAT, askorbat-peroksidaza - APX), sadržaj fotosintetskih pigmenata (ukupni klorofil - Chl, karotenoidi - Car) i temperature lista (LT) hibrida suncokreta tijekom dviju vegetacijskih sezona (2021. i 2022.).

Factor / *Faktor*	F_V/F_M		PI_{ABS}		**Phenolics** / *Fenoli*		**DPPH**			
	F	p	F	p	F	p	F	p		
Hybrid / *Hibrid (H)*	42.775*	0.000*	32.000*	0.000*	1.175	0.342	3.245	0.074		
Year / *Godina (Y)*	0.363	0.548	72.852*	0.000*	68.632*	0.000*	1.372	0.264		
H × Y	4.420*	0.014*	11.936*	0.000*	1.249	0.321	7.873*	0.007*		
Factor / *Faktor*	**CAT**		**APX**		**Chl**		**Car**		**LT**	
	F	p	F	p	F	p	F	p	F	p
Hybrid / *Hibrid (H)*	11.868*	0.000*	0.616	0.549	17.154*	0.000*	15.310*	0.000*	4.084*	0.020*
Year / *Godina (Y)*	194.705*	0.000*	9.402*	0.005*	201.505*	0.000*	20.189*	0.000*	9.532*	0.003*
H × Y	11.578*	0.000*	16.280*	0.000*	50.638*	0.000*	31.460*	0.000*	0.072*	0.931

F_V/F_M - maximum quantum efficiency of photosystem II, PI_{ABS} - performance index, DPPH - 2,2-diphenyl-1-picrylhydrazyl - F_V/F_M - maksimalna kvantna učinkovitost fotosustava II, PI_{ABS} - indeks fotosintetske učinkovitosti

Chlorophyll Fluorescence Parameters

F_V/F_M was relatively stable over the years, with no significant differences between 2021 and 2022 within individual hybrids (fig. 2). However, significant hybrid differences were observed, as Matej (0.84 and 0.83) and OS-H-17 (0.84 and 0.84) hybrids maintained significantly higher F_V/F_M values compared to Luka (0.81 and 0.81), which had lower values in both years of testing. These results suggest that F_V/F_M is under stronger genetic control than environmental control, a finding also reported by Murchie and Lawson (2013) and Cheng et al. (2024) in their studies. On the contrary, a more common case is the occurrence of sensitivity of F_V/F_M to environmental conditions, particularly the presence of stress on plants (Umar et al., 2019; Hammami et al., 2024; Mihaljević et al., 2025). In contrast, PI_{ABS} showed greater variability, reflecting both hybrid and environmental influences. It is noticeable that higher PI_{ABS} values were achieved by all hybrids in 2022. The OS-H-17 hybrid had the highest PI_{ABS} value (6.54) in 2022, significantly outperforming both Luka (4.29) and Matej (5.21), whereas in 2021, its values were lower. The Luka hybrid consistently showed the lowest PI_{ABS} values in both years (2.49 and 4.29). The strong effect of the year suggests that PI_{ABS} is more sensitive to environmental variations than F_V/F_M, probably because it integrates several functional energy conversion steps, rather than just the maximum photochemical efficiency. Overall, these results confirm that, although F_V/F_M remains a relatively stable indicator of PSII efficiency in these tested conditions, PI_{ABS} is more sensitive to genotypic differences and environmental conditions. Stated, making it a sensitive parameter for detecting tolerance and photosynthetic efficiency in sunflower hybrids, as previously confirmed by Hu et al. (2023) and Stefanov et al. (2022).

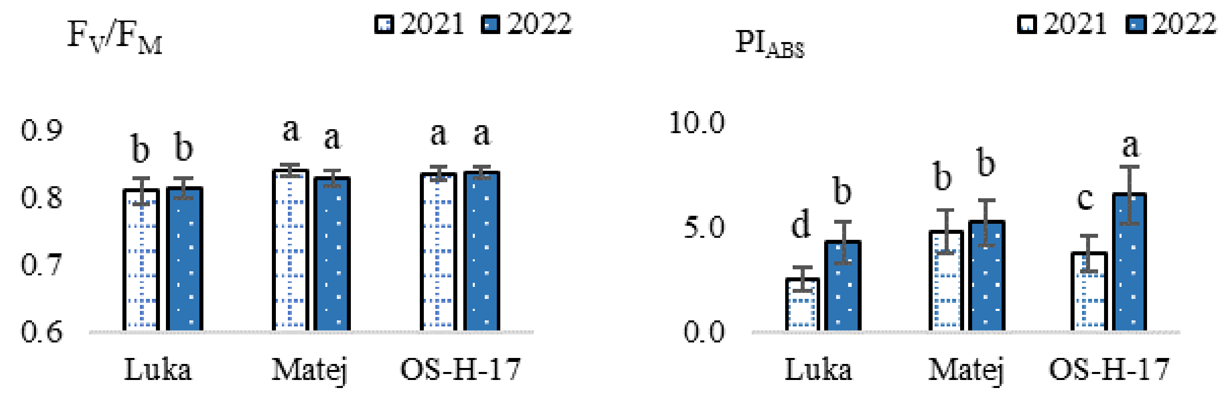

Figure 2. Maximum quantum efficiency of photosystem II (F_V/F_M) and performance index (PI_{ABS}) of sunflower hybrids in 2021 and 2022.

Grafikon 2. Maksimalna kvantna učinkovitost fotosustava II (F_V/F_M) i indeks fotosintetske učinkovitosti (PI_{ABS}) hibrida suncokreta u 2021. i 2022. godini.

Phenolic and DPPH

Since phenolics were only significant for a year as a source of variability, the data were processed separately by year (fig. 3). In 2021 (3.27 mg/g fresh weight (FW), significantly higher phenolic levels were observed compared to 2022 (2.53 mg/g FW), highlighting the dominant influence of environmental conditions on phenolic metabolism. Phenolics are secondary metabolites that are often induced to synthesise under stress conditions, such as drought, high temperatures, and UV radiation (Zagoskina et al., 2023). Gai et al. (2020) proved that phenolic components depend on the development stages of sunflower, establishing the highest total phenolic content in the mid-flowering growth stage. In contrast, DPPH activity showed less year-to-year fluctuations but pronounced hybrid differences (fig. 3). The OS-H-17 hybrid (11.78 mg TROLOX/g) showed the highest antioxidant capacity, especially in 2021, while Luka showed consistently lower values in both years (9.07 and 9.13 mg TROLOX/g, respectively). Compared to phenolics, DPPH activity in this study appears to be more strongly determined by genetic background than by environmental variation, suggesting that hybrid-specific antioxidant potential is a relatively stable trait. However, this claim is not in line with previous research, as the antioxidant status of a plant depends largely on crop type, cultivation method and biochemical pathways. For example, in wheat, antioxidant capacity and total phenolic content are susceptible to environmental variation, despite a notable role for genotype (Žilić et al., 2011; Shewry and Hey, 2015).

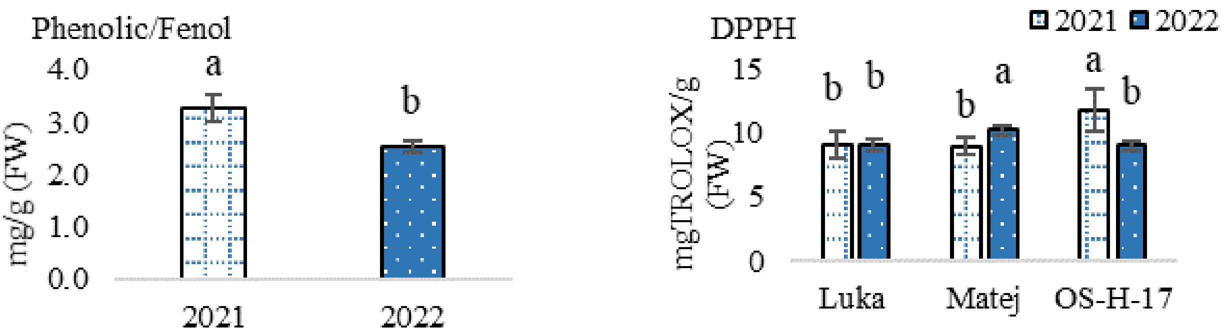

Figure 3. Phenolic content and DPPH (2,2-diphenyl-1-picrylhydrazyl) activity of sunflower hybrids in 2021 and 2022.

Grafikon 3. Sadržaj polifenola i DPPH (2,2-diphenyl-1-picrylhydrazyl) aktivnost hibrida suncokreta u 2021. i 2022. godini.

Antioxidative Enzymes

Catalase, the predominant peroxisomal antioxidant enzyme in plants, decomposes H_2O_2 generated during mitochondrial electron transport, fatty acid oxidation, and, most importantly, photorespiratory oxidation under both normal and stress conditions, thereby preventing cellular oxidative damage (Ahmad et al., 2011). Catalase activity (Figure 4) showed an apparent increase in 2022 compared to 2021 for all hybrids. In 2021, the lowest activity was observed in Matej (approximately 80 nkatal/$mg_{proteins}$), followed by OS-H-17 (approximately 115 nkatal/$mg_{proteins}$) and Luka (approximately 110 nkatal/$mg_{proteins}$), without significant differences among hybrids. In 2022, Luka exhibited the highest catalase activity (approximately 260 nkatal/$mg_{proteins}$), significantly higher than Matej and OS-H-17 (approximately 210 and 170 nkatal/$mg_{proteins}$, respectively). This trend suggests a stronger antioxidant response in 2022, possibly due to environmental conditions that enhance the relative oxidative species (ROS) scavenging mechanisms. Complementarily, ascorbate peroxidase, a key component of the ascorbate-glutathione cycle, utilises ascorbate as an electron donor to reduce H_2O_2 into water, thereby maintaining redox homeostasis across chloroplasts, mitochondria, peroxisomes, and the cytosol, and providing an additional protective mechanism against oxidative stress (Saxena et al., 2023). Ascorbate peroxidase activity (Figure 4) showed moderate variations between hybrids and years. Luka and OS-H-17 showed similar APX activity in both years, while Matej showed a significant increase from 2021 (approximately 0.58 nkatal/$mg_{proteins}$) to 2022 (approximately 1.05 nkatal/$mg_{proteins}$), indicating a modulation of antioxidant activity depending on the growing season. Overall, Luka showed the highest stability of APX activity over the years, suggesting a more consistent capacity to detoxify hydrogen peroxide. The observed differences in CAT and APX activity among hybrids and years likely reflect genotype-specific responses to environmental conditions and oxidative stress. Higher enzyme activities in 2022 indicate improved ROS scavenging, which may contribute to enhanced stress tolerance and improved plant performance. These findings are consistent with previous studies, which indicate that both CAT and APX are crucial for protecting plant cells from oxidative damage under changing environmental conditions (Sousa et al., 2019).

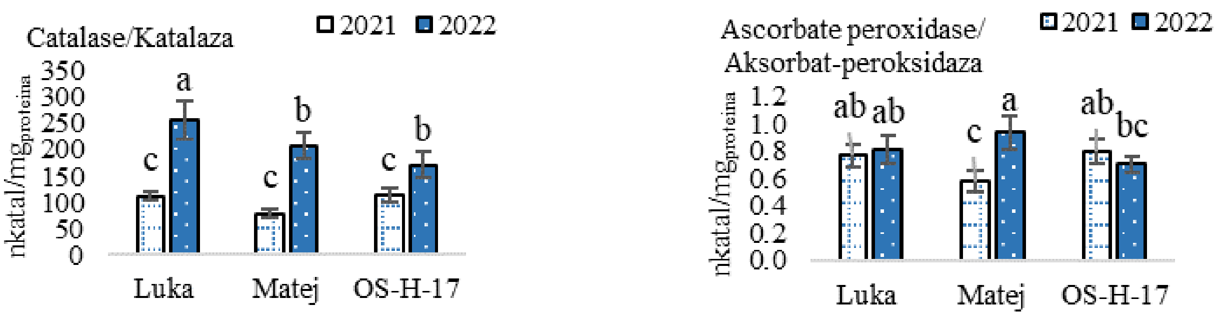

Figure 4. Catalase and ascorbate peroxidase activity of sunflower hybrids in 2021 and 2022.

Grafikon 4. Aktivnost enzima katalaza i askorbat-peroksidaza hibrida suncokreta u 2021. i 2022. godini.

Photosynthetic Pigment Concentrations

Total chlorophyll concentrations differed among hybrids and between years (fig. 5). Notably, Luka showed a pronounced increase in total chlorophyll in 2022 (1.47 mg/g FW) compared with 2021 (0.92 mg/g FW). On the other hand, Matej (1.28 and 1.35 mg/g FW) and OS-H-17 (1.21 and 1.43 mg/g FW) maintained relatively stable values across the two years. The observed increase in 2022 for Luka may indicate more favourable environmental conditions or reduced stress during the growing season. In contrast, carotenoid concentrations were less variable across years and hybrids. Luka exhibited a moderate increase in 2022 (0.32 mg/g FW), while Matej and OS-H-17 remained largely unchanged over the years (fig. 5). The stability of carotenoid content across hybrids and years suggests maintained photoprotective capacity under varying environmental conditions (Sun et al., 2022).

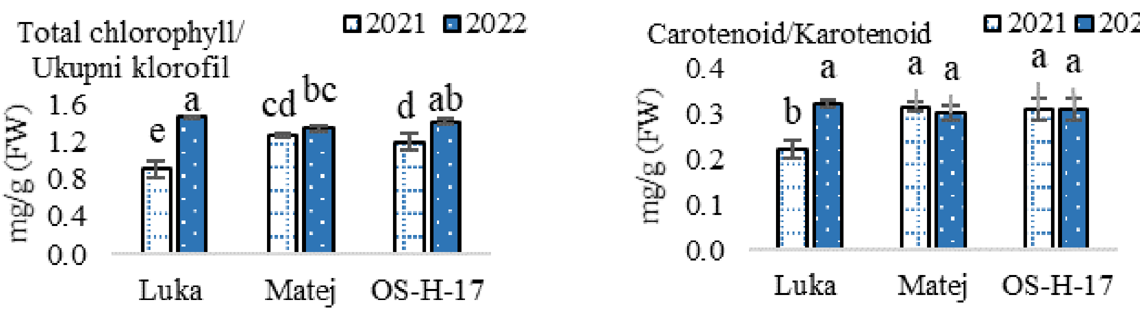

Figure 5. Total chlorophyll and carotenoids of sunflower hybrids in 2021 and 2022.

Grafikon 5. Ukupni klorofili i karotenoidi hibrida suncokreta u 2021. i 2022. godini.

Leaf Temperature

Leaf temperature showed statistically significant differences between hybrids and years of study. Luka had the highest average leaf temperatures in both years (22.13 °C), followed by Matej (21.54 °C) and OS-H-17 (21.22 °C;fig. 6a). A statistically significantly higher leaf temperature was recorded in 2021 (22.03 °C) compared to 2022 (21.22 °C; fig. 6b). Leaf temperature is determined by a combination of physical and physiological properties of the leaf and environmental conditions (Zhou et al., 2023). That is, it is related to the radiation and heat exchange of the environment. The ambient temperature differs from the leaf temperature by up to 5 °C (van Westreenen et al., 2020). In this study, such large differences were not expressed because the measurements were taken during the morning hours, when the radiation was not yet intense.

Considering all the results presented, the interannual variability of physiological and biochemical traits can largely be explained by differences in environmental conditions between 2021 and 2022. The higher temperatures and irradiance conditions in 2021, which were reflected in higher ambient and leaf temperatures, as well as increased PPFD, were associated with reduced PI_{ABS} and increased phenolic accumulation. The more intensified oxidative activity of plants can explain this. In contrast, slightly cooler conditions and lower light irradiance in 2022 favoured higher PI_{ABS} values, increased chlorophyll content, and improved antioxidant enzyme activity (CAT and APX).

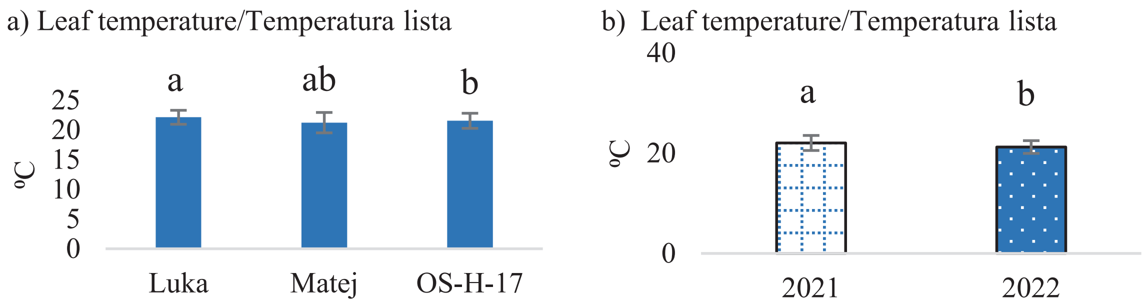

Figure 6. a) Average leaf temperature per hybrid; b) average leaf temperature per year.

Slika 6. a) Prosjek temperature lista po hibridima; b) prosjek temperature lista po godini.

Principal Component Analysis (PCA)

Two principal components, explaining 71.78% of the total variance (PC1: 44.01%, PC2: 27.77%), were extracted by PCA (Figure 7). PC1 is strongly positively associated with PI_{ABS} (r = 0.353), total chl (r = 0.371), car (r = 0.282), and CAT activity (r = 0.291). Conversely, negative loadings were found for phenolics (r = -0.324) and LT (r = -0.366). From the above, it can be observed that plants with higher photosynthetic efficiency, pigment concentration and more efficient catalase activity are divided from those with higher accumulation of secondary metabolites and increased LT.

On the other hand, PC2 showed strong positive relationships with F_V/F_M (r = 0.478), phenolics (r = 0.270) and car (r = 0.226), and negative relationships with CAT (-0.320) and APX (r = -0.260). This component, therefore, represents a balance between photochemical efficiency, photoprotective pigments and an enzymatic antioxidant system.

The position of the hybrids in the PCA determined their different phenotypes. Matej and OS-H-17 were positioned towards the positive side of PC2, associated with higher F_V/F_M and phenolics. Luka was separated along the negative PC2 axis, which reflects a stronger dependence on enzymatic antioxidant mechanisms (CAT and APX). Considering treatments, 2021 was negatively positioned on PC1, associated with higher LT and phenolic accumulation, while 2022 was positively positioned on PC1, reflecting higher chlorophyll levels, photosynthetic efficiency and antioxidant enzyme activity. This trade-off between primary (photosynthetic) and secondary (phenolic) metabolism is a common adaptive strategy under stress (Kostidis and Karabourniotis, 2024).

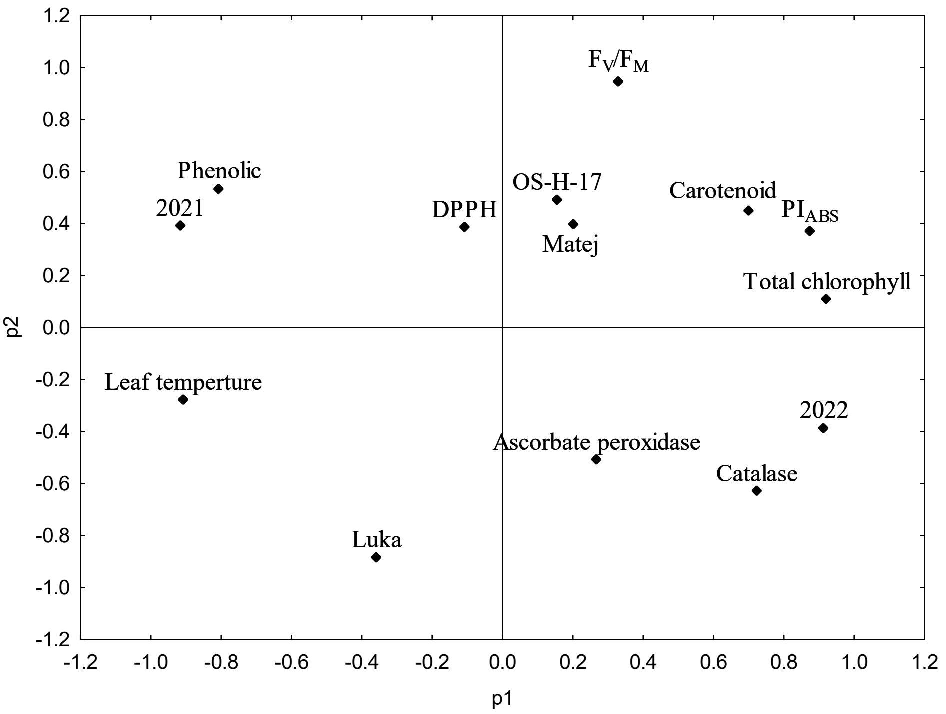

Figure 7. Biplot of sunflower hybrids (Luka, Matej, and OS-H-17) and variables based on principal components (PC1 and PC2). F_V/F_M—maximum quantum efficiency of photosystem II and PI_{ABS}—performance index.

Grafikon 7. Biplot hibrida suncokreta (Luka, Matej i OS-H-17) i varijabala temeljenih na glavnim komponentama (PC1 i PC2). F_V/F_M — maksimalna kvantna učinkovitost fotosustava II i PI_{ABS} — indeks fotosintetske učinkovitosti.

CONCLUSION

The results of this study demonstrated genotype differences in the early physiological and biochemical responses of three sunflower hybrids under two different seasonal conditions. Higher temperatures and irradiance in 2021 compared to cooler conditions in 2022 significantly influenced photosynthetic efficiency, pigment composition, and antioxidant activity. PI_{ABS} has shown specific differences in photosynthetic performance for each year and hybrid, unlike F_V/F_M, which has proven to be a less sensitive parameter. Enzymatic (CAT and APX) and non-enzymatic (phenolics and DPPH) antioxidants revealed distinct hybrid strategies in regulating oxidative stress. According to PCA, it was established that Luka showed stability through the consistency of chlorophyll content and enzymatic antioxidant activity. In contrast, Luki, Matej, and OS-H-17 relied more on non-enzymatic defences, reflecting less stable but more flexible responses. Therefore, Luka showed the most consistent stability in several properties, which suggests a greater ability to maintain physiological and biochemical homeostasis in changing environmental conditions in the early stage of vegetative development. These findings indicate that the resistance specific to hybrids is strongly influenced by genetic background and interaction with the environment, and provide the basis for identifying stable sunflower genotypes for growing in variable climate conditions.

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FIZIOLOŠKI I BIOKEMIJSKI ODGOVORI HIBRIDA SUNCOKRETA U POLJSKIM UVJETIMA

SAŽETAK

U ovome istraživanju istraženi su fiziološki i biokemijski odgovori triju hibrida (Luka, Matej i OS-H-17) suncokreta (Helianthus annuus L.) u poljskim uvjetima u 2021. i 2022. godini. Prema analiziranim podatcima, uočena je značajna varijabilnost godine. U 2021. godini više temperature okoline i lista, kao i zračenje, dovele su do smanjenoga indeksa fotosintetske učinkovitosti (PI_{ABS}) i povećane akumulacije fenola. U 2022. godini nešto hladniji uvjeti s nižim zračenjem pogodovali su većem sadržaju klorofila, PI_{ABS} te većim aktivnostima enzima katalaze i aksorbat-peroksidaze. Analiza glavnih komponenata odvojila je godine i diferencirala hibride prema njihovim strategijama odgovora. Luka je povezan sa stabilnošću klorofila i enzimskim antioksidansima, dok su se Matej i OS-H-17 više oslanjali na neenzimske mehanizme. Stoga varijacije u okolišu imaju značajan utjecaj na fiziologiju i biokemijske odgovore suncokreta. Hibridi su pokazali specifične karakteristike povezane s adaptivnim mehanizmima. Luka je pokazao najstabilnije antioksidativne i fotosintetske performanse, što naglašava važnost hibridne selekcije u proizvodnji suncokreta otpornih na klimu.

Ključne riječi: F_V/F_M, PI_{ABS}, ***antioksidativna aktivnost, pigmenti, godina***

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