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Original scientific article

SUNFLOWER AGRONOMIC TRAITS IN FIELD IRRIGATION CONDITIONS

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Multi-year studies are crucial for the evaluation of sunflower hybrids and quantifying the environmental effect in the expression of genetic potential. In order to assess the adaptation of eight hybrids and test the impact of water availability on plant height (PH), head diameter (HD), 1000-grain weight (TWG), hectolitre mass (HM), seed yield (SY), oil content (OC) and oil yield (OY), a two-year study was conducted with irrigation as treatment. Analysis of variance (ANOVA) and principal component analysis (PCA) confirmed the year influence on all tested agronomic traits. According to the three-way ANOVA, irrigation significantly affected all tested traits except HD, OC and OY. All agronomic traits had lower values in both rainfed and irrigated treatment in 2014, confirming the influence of the environment. The hybrid was a significant source of variation for all traits. ANOVA and PCA grouped hybrids 1, 7, and 8 in one group and 2, 3, 4, 5, and 6 in another. The first group had lower PH, HD, TGW and SY values and higher HM, OC and OY values, and the second group had reversed traits values. Furthermore, the PCA biplot indicates SY was positively correlated with PH, HD, TGW and OY and HM was positively correlated with OC. This facilitates the breeding process because it enables indirect breeding for economically important traits such as seed yield, oil content and oil yield. As treatments were significant sources of variation for PH, HM, TWG and SY, sunflower irrigating is considered justified and

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can be used as an additional agrotechnical measure to target the agronomic traits. Understanding the expression of traits under rainfed and irrigation conditions will greatly help design effective breeding programs by creating hybrids suitable for cultivation in semi-arid environments.

Keywords: *Helianthus annuus* L., Environment, Water availability, Agronomic properties, Yield

INTRODUCTION

Lack of precipitation, i.e. drought, is a major environmental constraint occurring in many parts of the world every year (DARVISHZADEH *et al.*, 2014). The occurrence of drought, extremely high temperatures, and excess sunlight intensity, especially from the early phases until the plant is fully developed, can cause stress and significantly impact production in most crops. Sunflower is potentially a drought-tolerant plant. A deep and robust root drawing water from deeper soil layers enables the sunflower's partial adaptation to high temperatures and drought (HUSSAIN *et al.*, 2018). Critical periods in the development of sunflowers in the absence of water are the phase of formation and appearance of flower buds and the phase of flowering (VRATARIĆ *et al.*, 2004), in which, due to lack of water, the seed filling is reduced (DARVISHZADEH *et al.*, 2014). Most worrying is the fact that under significant climate changes we are witnessing, dry periods during the vegetation of summer crops, among which is the sunflower, occur more often than in the recent past. Therefore, in arid regions where water is a limiting factor of arable land and yield per unit area, the study of the effect of irrigation on agriculture is of utmost importance (SEGHATOLESLAMI *et al.*, 2012).

In 2009–2018, the sunflower was grown in the European Union (EU) on over 4175871 hectares, with an average seed yield of 2.85 t/ha (FAOSTAT, 2021). Although sunflower share in the utilised agricultural area in the Republic of Croatia is small (2.48% according to the Statistical Yearbook of the Republic of Croatia), according to an average of 10 years (2009–2018), cultivated hybrids reach the highest seed yield (2.85 t/ha), taking a significant first place compared to the other EU Member States. Sunflower has become the most important oilseed crop among different crops grown in the country due to its high yield potential and short vegetation, thus enabling the timely sowing of winter crops in temperate continental climates. The advantage of the sunflower crop is its wide adaptability under different climatic conditions. For this reason, HUSSAIN *et al.* (2017) emphasised the need to develop sunflower hybrids with better performance of agronomic traits in the current climate change scenario. High-yielding crops with improved stability make agricultural systems less susceptible to climate change which is essential for food safety. Creating new lines and hybrids with high seed and oil yields for fulfilling the needs of humans and farm animals is the main goal of sunflower plant breeding. Agronomic traits largely depend on different years, localities, hybrids, and interactions (BALALIĆ *et al.*, 2012). PEPÓ and NOVAK (2016) stated that in addition to creating more productive hybrids, the use of agro-technical measures that reduce the impact of limiting factors in production is very important, thus contributing to the increase in sunflower yield. To achieve a high yield of hybrids in practice, MAZVIMBAKUPA *et al.* (2015) also noted that in addition to choosing a good hybrid applying optimal agrotechnics and irrigation according to the recommendations, it is necessary to use declared seeds of known quality for sowing. For this reason, it is necessary to continually change the assortment with more productive and stable sunflower hybrids that are more fertile and of better quality (JOKIĆ *et al.,* 2016), which is achieved by plant breeding. Plant breeding may be used for manipulating agronomic traits. For sunflowers, agronomic traits such as plant height (PH) and head diameter (HD) are important for yield expression. There are large variations in PH between sunflower lines and hybrids. Breeders prefer shorter plants because they can usually support higher yields. Plants which range from 120 to 150 cm are more resistant to lodging caused by unfavourable environmental conditions, which is crucial when creating new lines. Also, it ultimately makes it easier to harvest shorter hybrids mechanically (ĆIRIĆ *et al.*, 2012). The size of the sunflower head, i.e. its diameter, is an important factor that affects the seed yield (SY) per plant and unit area by influencing the number of seeds per head and the size of the seed itself (BALALIĆ *et al.,* 2016). Sunflower yield depends on the hectolitre mass (HM) and 1000-grain weight (TGW) as well. The environment significantly influences both traits. According to MIJIĆ *et al.* (2006), HM is important in seed processing because, on its basis, the quality of seed production can be estimated. The low HM indicates poorer seed production and seed quality KOLAK (1994). On the other hand, TGW is an essential criterion for successful sunflower production because farmers use it when determining the norm and sowing method. At the same time, it determines the seed quality and yield per unit area (RADIĆ *et al.,* 2013). The TGW is directly related to the SY. High SY, oil content (OC), and oil yield (OY) per unit area are the primary goals of sunflower producers, and at the same time, sunflower breeders pay the most attention to them. Most agronomic traits are inherited quantitatively, and it is generally known that quantitative traits are a product of the influence of genotypes, the environment, and their interactions during the vegetation (BALALIĆ *et al.*, 2012). A successful breeding program is determined by selecting genotypes suitable for breeding in different environmental conditions while retaining their desirable characteristics. Therefore, this study aimed to investigate the adaptability of eight sunflower hybrids in different environmental conditions. We hypothesised that year, irrigation, and hybrid influence on the examined agronomic traits is significant and therefore proven. Moreover, we hypothesised that irrigation plays a major role in sunflower hybrids responses and further adaptation to environmental conditions. Irrigation at critical phases of development enabled the investigation of water availability impact on morphological traits, which can serve as tools in assessing adaptation to environmental conditions.

MATERIALS AND METHODS

Experimental materials and design

The experiment was conducted on eight sunflower hybrids (H1–H8) chosen for this study based on previous trial results. Six hybrids were developed at the Agricultural Institute Osijek (Osijek, Croatia), and two hybrids were standards. Hybrids differed in pedigree and agronomic traits. The study was conducted in the field (45°32'N, 18°44'E) in 2013 and 2014. Sowing in sandy clay loam soil was performed at 4 cm depth, in four 5 m long rows per plot with 70 cm distance between rows and 23 cm distance within a row with hand planters. The experiment consisted of two treatments and four replications. The first treatment represented rainfed conditions, and the second treatment represented irrigated conditions. During the experiment, all agro-technical measures were performed according to the requirements and recommendations for sunflower cultivation.

Irrigation of the experimental field

Granular matrix sensors (Watermark Model 200SS, California) were placed into the soil at 10–15 cm and 25–30 cm depth. They were previously calibrated by the gravimetric method and used for estimating soil moisture based on which the irrigation time was determined. Recording soil water content was performed with a digital soil moisture meter (Watermark, Irrometer Company, Inc. Riverside, California) twice a week. Values on the watermark of about 80 cbar marked the beginning of the irrigation. Water used for irrigation was pumped from a 37 m deep well with a 5.5 kW electric pump and was suitable for irrigation according to the recommendation. A travel sprinkler system was used to irrigate an area about 28 meters long with an efficiency of about 95%. Experimental irrigation treatment plots in 2013 were irrigated four times (beginning of stem elongation, butonisation, before flowering, and full flowering), and a total of 97 mm of water was added during the vegetation. In 2014, 25 mm of water was added in one application (before flowering). The lower need for irrigation in 2014, compared to 2013 (Figure 1), was due to a higher rainfall amount. During the sunflower vegetation in 2014, more rain fell than in the long-term average. Irrigation was carried out during the morning or evening to protect plants from burns.

Agronomic traits

Plant height (PH; cm) and head diameter (HD; cm) were measured at the physiological maturity of the sunflower (HLADNI *et al.*, 2014). They were expressed as the average of 20 measured values (five plants per replicate) per hybrid. In contrast, hectolitre mass (HM; kg/hl), 1000-grain weight (TGW; g), yield seed (SY; t/ha) and oil content (OC; %) were determined after the harvest from a bulk sample containing seeds of each plant from two middle rows per hybrid. The HM was determined on a Dickey John GAC 2000–Grain analysis computer (USA) three times per sample. The TGW was determined according to the Ordinance on methods of sampling and testing of seed quality. Eight 100 seed samples were weighed per replicate, and the average values were used for statistical analyses. SY is calculated at the level of 9% moisture and 2% impurities. After harvesting, the seed moisture was determined for each sample using a Dickey John GAC 2000–Grain analysis computer (USA) device. The weight of each sample was determined on a DefenderTM 3000 scale (Ohaus Corporation, New Jersey, USA). The SY was calculated according to the formula: SY (t/ha) = weight × 10 / 7 × (100 - sample moisture) / 91, where 7 is the size of the plot in m^2. Before determining the OC, each sample was manually cleaned of impurities, and 150 mL of seeds required for analysis were used. OC was determined using the device MQA 7005 NMR Analyser–Nuclear Magnetic Resonance (UK). The OC on a dry matter (DM) basis was calculated according to the formula: OC at DM (%) = oil × 100 / (100 - moisture). OY was determined according to the formula, using SY and OC: OY (t/ha) = SY × 0.91 x OC at DM / 100. SY, OC and OY were calculated by averaging the four measured values (one per replicate).

Data analysis

The results are shown as the average values. Three-way analysis of variance (ANOVA), with year, treatment and hybrid as factors, was used for analysing agronomic data. ANOVA was also used to compare agronomic traits by treatments and hybrids per year. To determine differences between treatments and sunflower hybrids, the post hoc Fisher's LSD test was used at $P < 0.05$. Correlation among years, treatment and hybrids were explored by principal component analysis (PCA). The software used for statistical analyses was Statistica 12.

RESULTS AND DISCUSSION

Weather conditions

Years 2013 and 2014 (Figure 1), during the sunflower field experiment, had 472.6 and 611.2 mm of rain fell, respectively. The average air temperature in 2013 and 2014 in sunflower vegetation was 17.9 °C and 17.5°C, respectively. Although both years had similar average air temperatures during sunflower vegetation, which were very near the long-term average (17.8 °C), 2014 had more precipitation than 2013 (Figure 1). In May of both research years, before seed germination and initial plant development, recorded precipitation (119.0 mm in 2013 and 161.4 mm in 2014) was above the long-term average (86.8 mm). The precipitation was above the long-term average (59.2 mm) in September of 2013 (123.7 mm), i.e. during the sunflower grain filling phase, as well. The vegetation period in 2013 was unevenly supplied with precipitation, and the highest lack of precipitation was observed during the rapid growth phase when the sunflower has the greatest water needs, i.e. about 43% of the total water required for vegetation (VRATARIĆ *et al.,* 2004). During the rapid growth phase in 2013, sunflower only got 63.3 mm of precipitation in June and 36.5 mm in July, with average air temperatures of 20.0°C (June) and 22.9°C (July). In comparison, in 2014, the average air temperatures were lower than the long-term average in the same phase. In the flowering and maturing phase, sunflower also needs a significant amount of available water and nutrients due to the intensive accumulation of dry matter (accumulates about 50%), and the optimal air temperature is about 20°C to 22°C (VRATARIĆ *et al.,* 2004; POSPIŠIL, 2013). In 2013, July and August had the same average temperatures (22.9°C), which was above optimal, but in September (15.9°C), the average temperature was below optimal. In 2014, the average air temperature in July and August (21.9°C and 20.8°C) corresponded to the optimal values, but in September, the temperature was below optimal (17.0°C).

In conclusion, although the amount of precipitation and the average temperatures were approximately equal in both experimental years, 2014 had a more uniform precipitation distribution with some extremes (April and May), which was reflected in the tested traits in 2014. On average, about 300 mm of precipitation is needed during the vegetation for a normal sunflower growth and development, but the amounts vary depending on whether it is grown in drier areas (500–700 mm) or wetter conditions (300–500 mm) (POSPIŠIL, 2013). Although there was a sufficient amount of precipitation in both years of research and optimal average air temperatures, the distribution of precipitation and the duration of maximum daily air temperatures were not satisfactory, which directly affected the length of individual development phases and thus the agronomic traits. Cumulative effects of environmental conditions, such as temperature, light levels, and available water, alter not only the plant phenology but they cause a number of physiological and qualitative changes, including changes in crop growth, development, yield, and oil accumulation as well (DEBAEKE *et al.,* 2017).

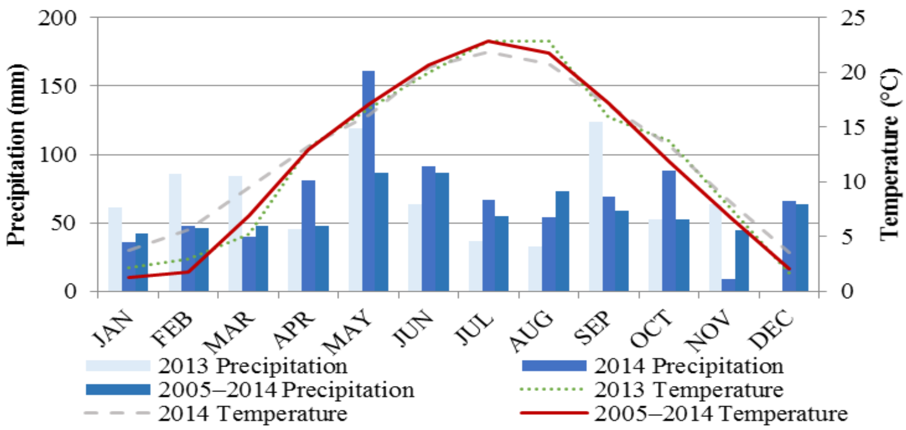

Figure 1. Precipitations (mm) and average air temperatures (°C) in 2013 and 2014 and the long-term average of precipitations and temperatures (2005–2014) in Osijek (Croatian Meteorological and Hydrological Service).

Analysis of variance

ANOVA confirmed statistically significant differences at 5% between years (2013 and 2014) and sunflower hybrids (H1–H8) for all agronomic traits (Table 1). HD, OC, and OY were not statistically significant between treatments (rainfed and irrigated), unlike PH, HM, TGW and SY. The year x treatment interaction (Y x T) was not a statistically significant source of variation for HM and TGW. In contrast, the year x hybrid interaction (Y x H) was significant for all traits except TGW. The treatment x hybrid interaction (T x H) was not significant as a source of variation for TGW, PH and OC. The interaction year x treatment x hybrid (Y x T x H) was significant only for SY and OY.

*Table 1. Analysis of variance (mean squares and significance at P < 0.05 - *) for agronomic traits in tested years (2013 and 2014), treatments (rainfed and irrigated) and sunflower hybrids.*

Source of variation	Plant height	Head diameter	Hectolitre mass	1000-grain weight	Seed yield	Oil content	Oil yield
Year (Y)	7728.40*	145.35*	195.03*	4520.82*	22.52*	193.10*	6.94*
Treatment (T)	8208.22*	9.26	57.24*	144.50*	0.25*	0.58	0.06
Hybrid (H)	16385.72*	70.74*	91.77*	763.94*	3.60*	173.04*	0.58*
Y x T	4264.22*	19.25*	1.76	4.65	1.70*	9.90*	0.48*
Y x H	375.10*	10.83*	2.62*	17.10	0.92*	13.43*	0.25*
T x H	138.24	10.86*	1.58*	4.34	0.24*	0.44	0.05*
Y x T x H	74.02	5.77	1.13	7.42	0.15*	0.47	0.04*

Agronomic traits

Table 2 (2013) and Table 3 (2014) listed the agronomic traits values of treatments and sunflower hybrids.

Table 2. Average values of agronomic traits with treatments and hybrids for 2013

Trait	Treatment	Hybrid 1	Hybrid 2	Hybrid 3	Hybrid 4	Hybrid 5	Hybrid 6	Hybrid 7	Hybrid 8	Average
Plant height (cm)	Rainfed	187.15^{d}	216.75^{b}	227.15^{a}	196.95^{c}	221.55^{ab}	215.95^{b}	196.95^{c}	181.10^{d}	205.44^{B}
	Irrigated	198.00^{e}	230.00^{b}	237.95^{a}	211.85^{d}	233.45^{ab}	220.65^{c}	214.20^{cd}	196.05^{e}	217.77^{A}
	Average	**192.58^{E}**	**223.38^{BC}**	**232.55^{A}**	**204.40^{D}**	**227.50^{AB}**	**218.30^{C}**	**205.58^{D}**	**188.58^{E}**	
Head diameter (cm)	Rainfed	18.35^{bcd}	20.30^{a}	19.05^{abcd}	18.50^{bcd}	19.90^{ab}	18.25^{cd}	17.65^{d}	19.30^{abc}	18.91^{NS}
	Irrigated	18.60^{cde}	21.40^{a}	19.55^{bc}	18.10^{de}	20.30^{ab}	19.05^{bcd}	17.25^{e}	17.90^{de}	19.02^{NS}
	Average	**18.48^{CD}**	**20.85^{A}**	**19.30^{BC}**	**18.30^{CD}**	**20.10^{AB}**	**18.65^{BC}**	**17.45^{D}**	**18.60^{C}**	
Hectolitre mass (kg/hl)	Rainfed	44.18^{a}	40.68^{c}	41.85^{bc}	37.83^{d}	38.38^{d}	43.20^{ab}	43.70^{ab}	44.15^{a}	41.74^{B}
	Irrigated	45.80^{a}	42.38^{c}	43.28^{c}	39.40^{c}	41.25^{d}	44.65^{b}	45.13^{ab}	44.65^{b}	43.32^{A}
	Average	**44.99^{A}**	**41.53^{C}**	**42.56^{C}**	**38.61^{E}**	**39.81^{D}**	**43.93^{B}**	**44.41^{AB}**	**44.40^{AB}**	
1000-grain weight (g)	Rainfed	51.50^{f}	63.53^{d}	76.25^{a}	66.83^{cd}	71.35^{b}	71.20^{bc}	65.48^{d}	57.08^{e}	65.4^{A}
	Irrigated	51.65^{e}	61.65^{cd}	70.78^{a}	65.33^{bc}	70.68^{a}	68.73^{ab}	60.53^{d}	53.83^{e}	62.89^{B}
	Average	**51.58^{F}**	**62.59^{D}**	**73.51^{A}**	**66.08^{C}**	**71.01^{AB}**	**69.96^{B}**	**63.00^{CD}**	**55.45^{E}**	
Seed yield (t/ha)	Rainfed	3.97^{c}	5.06^{a}	5.00^{a}	4.35^{bc}	4.65^{ab}	4.75^{ab}	4.42^{bc}	4.79^{ab}	4.62^{B}
	Irrigated	4.68^{c}	5.94^{a}	5.16^{b}	5.01^{bc}	4.88^{bc}	4.93^{bc}	4.27^{d}	4.67^{c}	4.94^{A}
	Average	**4.32^{D}**	**5.50^{A}**	**5.08^{B}**	**4.68^{C}**	**4.77^{BC}**	**4.84^{BC}**	**4.34^{D}**	**4.78^{C}**	
Oil content (% DM)	Rainfed	51.37^{b}	48.61^{c}	46.71^{cd}	46.30^{d}	42.13^{e}	46.76^{cd}	52.92^{ab}	54.53^{a}	48.67^{B}
	Irrigated	52.32^{b}	49.56^{c}	46.94^{d}	47.27^{d}	43.04^{e}	47.62^{d}	53.67^{a}	54.46^{a}	49.36^{A}
	Average	**51.85^{C}**	**49.09^{D}**	**46.82^{E}**	**46.78^{E}**	**42.58^{F}**	**47.19^{E}**	**53.29^{B}**	**54.49^{A}**	
Oil yield (t/ha)	Rainfed	1.86^{cd}	2.24^{ab}	2.13^{abc}	1.84^{cd}	1.78^{d}	2.02^{bcd}	2.13^{abc}	2.38^{a}	2.05^{B}
	Irrigated	2.23^{bc}	2.68^{a}	2.20^{bc}	2.15^{bc}	1.91^{d}	2.14^{bc}	2.08^{cd}	2.32^{b}	2.21^{A}
	Average	**2.04^{B}**	**2.46^{A}**	**2.16^{B}**	**2.00^{BC}**	**1.85^{C}**	**2.08^{B}**	**2.11^{B}**	**2.35^{A}**	

Average values of agronomic traits in columns for hybrids per treatment, followed by the same lowercase letter(s), are not significantly different. Average values of agronomic traits in columns for hybrid and rows for treatments, followed by the same uppercase letter(s), are not significantly different at $P < 0.05$. NS – not significant.

Table 3. Average values of agronomic traits with treatments and hybrids for 2014

Trait	Treatment	Hybrid 1	Hybrid 2	Hybrid 3	Hybrid 4	Hybrid 5	Hybrid 6	Hybrid 7	Hybrid 8	Average
Plant height (cm)	Rainfed	192.00^{de}	212.50^{ab}	220.00^{a}	201.00^{c}	213.50^{ab}	210.00^{b}	195.00^{cd}	185.25^{e}	203.66^{NS}
	Irrigated	192.25^{e}	212.50^{bc}	222.25^{a}	202.25^{d}	217.75^{ab}	211.25^{c}	202.25^{d}	184.75^{f}	205.66^{NS}
	Average	**192.13^{D}**	**212.50^{B}**	**221.13^{A}**	**201.63^{C}**	**215.63^{B}**	**210.63^{B}**	**198.63^{C}**	**185.00^{E}**	
Head diameter (cm)	Rainfed	18.95	18.70	18.25	18.25	18.95	18.25	17.25	17.85	18.31^{A}
	Irrigated	18.05^{ab}	19.15^{a}	18.75^{a}	18.65^{a}	18.10^{ab}	17.20^{b}	14.80^{c}	17.05^{b}	17.72^{B}
	Average	**18.50^{AB}**	**18.93^{A}**	**18.50^{AB}**	**18.45^{AB}**	**18.53^{AB}**	**17.73^{BC}**	**16.03^{D}**	**17.45^{C}**	
Hectolitre mass (kg/hl)	Rainfed	41.74^{a}	39.38^{b}	40.20^{b}	35.98^{c}	35.95^{c}	39.58^{b}	41.30^{a}	41.98^{a}	39.51^{B}
	Irrigated	42.25^{bc}	39.68^{d}	41.48^{c}	36.28^{f}	37.68^{e}	40.38^{d}	44.48^{a}	42.70^{b}	40.61^{A}
	Average	**42.00^{B}**	**39.53^{D}**	**40.84^{C}**	**36.13^{F}**	**36.81^{E}**	**39.98^{D}**	**42.89^{A}**	**42.34^{AB}**	
1000-grain weight (g)	Rainfed	44.78^{f}	49.40^{de}	62.59^{a}	55.54^{c}	59.93^{ab}	56.38^{bc}	50.60^{d}	45.86^{ef}	53.13^{A}
	Irrigated	42.36^{d}	50.64^{c}	60.90^{a}	52.89^{c}	56.85^{b}	53.43^{bc}	49.53^{bc}	44.53^{d}	51.39^{B}
	Average	**43.57^{E}**	**50.02^{D}**	**61.74^{A}**	**54.21^{C}**	**58.39^{B}**	**54.90^{C}**	**50.06^{D}**	**45.19^{E}**	
Seed yield (t/ha)	Rainfed	3.93^{d}	4.96^{a}	4.40^{c}	4.70^{d}	3.86^{d}	3.82^{d}	2.90^{f}	3.58^{e}	4.02^{A}
	Irrigated	3.95^{c}	4.81^{a}	4.10^{c}	4.52^{b}	3.93^{cd}	3.73^{d}	2.94^{e}	2.99^{e}	3.87^{B}
	Average	**3.94^{D}**	**4.89^{A}**	**4.25^{C}**	**4.61^{B}**	**3.89^{DE}**	**3.77^{E}**	**2.92^{E}**	**3.28^{F}**	
Oil content (% DM)	Rainfed	48.12^{bc}	47.96^{bc}	46.67^{cd}	44.71^{e}	41.69^{f}	45.43^{de}	50.37^{a}	49.17^{ab}	46.77^{NS}
	Irrigated	46.93^{bc}	47.26^{bc}	46.62^{cd}	43.83^{e}	41.83^{f}	45.26^{de}	50.68^{a}	48.35^{b}	46.35^{NS}
	Average	**47.53^{C}**	**47.61^{C}**	**46.64^{C}**	**44.27^{E}**	**41.76^{F}**	**45.35^{D}**	**50.53^{A}**	**48.76^{A}**	
Oil yield (t/ha)	Rainfed	1.72^{c}	2.16^{a}	1.87^{b}	1.91^{b}	1.46^{c}	1.58^{d}	1.33^{f}	1.60^{d}	1.70^{A}
	Irrigated	1.69^{c}	2.07^{a}	1.74^{bc}	1.80^{b}	1.50^{d}	1.54^{d}	1.36^{e}	1.32^{e}	1.63^{B}
	Average	**1.70^{C}**	**2.12^{A}**	**1.80^{B}**	**1.86^{B}**	**1.48^{E}**	**1.56^{D}**	**1.34^{F}**	**1.46^{E}**	

Average values of agronomic traits in columns for hybrids per treatment, followed by the same lowercase letter(s), are not significantly different. Average values of agronomic traits in columns for hybrid and rows for treatments, followed by the same uppercase letter(s), are not significantly different at $P < 0.05$. NS – not significant

Plant height

Although, according to VRATARIĆ *et al.* (2004), the height of sunflower plants can vary greatly (50–500 cm), commercial sunflower hybrids are usually in a range of 150–200 cm (HLADNI *et al.,* 2014), while the optimal height is considered to be between 150–170 cm. In this research, PH values in 2013 and 2014 in both rainfed and irrigated treatments and treatments average per hybrids were the lowest in hybrid 8 (rainfed: 181.10 and 185.25 cm; irrigated: 196.05 and 184.75 cm; treatments average: 188.58 and 185.00 cm, respectively) and the highest in hybrid 3 (rainfed: 227.15 and 220.00 cm; irrigated: 237.95 and 222.25 cm; treatments average: 232.55 and 221.13 cm, respectively). ĆIRIĆ *et al.* (2013) reported a very similar range of PH values when examining lines' combining abilities. The lowest value in hybrid was 182.7 cm, and the highest was 239 cm. Similar results were determined by IQRASAN *et al.* (2017). In contrast, UD-DIN *et al.* (2014) identified lower plants in their study (177–200 cm). Furthermore, in 2013 average plant heights in irrigated treatment were significantly higher than in rainfed treatment. In general, irrigation increased PH in 2013 by 6.00%. In 2014, the statistical significance of treatments for plant heights was not proven. RAUF *et al.* (2012) proved that omitting irrigation at the beginning of stem elongation causes a decrease in sunflower plants' height, which may be why irrigated plants had lower stems in 2014. Since lower plants are preferred, the impact of irrigation in 2013 was not favourable. RAUF *et al.* (2012) and EBEED *et al.* (2019) reported the same irrigation effect, i.e. increasing plants' height with irrigation. Unfortunately, plants higher than two meters had been lodging, more so in irrigated areas or during heavy autumn rains and in locations with strong wind currents during head maturation, leading to yield loss.

Head diameter

The HD depends on genotype, environmental factors, and cultivation agrotechnics (VRATARIĆ *et al.*, 2004; ŠKORIĆ, 2012; HLADNI *et al.*, 2014), and it was morphophysiological traits that indirectly affect the SY. Optimal HD depends on the purpose of use. For example, oil sunflower types have an HD between 15–25 cm, while non-oil genotypes can have an HD of up to 40 cm (VRATARIĆ *et al.*, 2004). According to BALALIĆ *et al.* (2016), the head's diameter should be 20–25 cm, with a firm epidermis on the head's underside. Shifts in the diameter of sunflower heads beyond optimal values lead to an increase in the number of empty seeds, an increase in the shell percentage, a decrease in SY and OC (ŠKORIĆ, 2012). In contrast, ĆIRIĆ *et al.* (2013) argue that hybrids with large head diameters and many fertile flowers are preferred. In this research, HD ranged from 17.25 (H7) to 21.40 cm (H2) in 2013. Both minimum and maximum values were in irrigated treatment, thus confirming a statistically significant difference between hybrids within the treatment. In 2014, the range was 14.80 (H7 in rainfed) to 19.15 cm (H2 in irrigated). According to the LSD test, hybrids in rainfed treatment did not show a statistical difference in HD. UD-DIN *et al.* (2014) recorded a minimum head size of 16.60 cm and a maximum of 19.90 cm in a hybrid combination, similar to results here in 2014. IQRASAN *et al.* (2017) received similar results as well. Conditions in 2013 were more favourable for the development of larger sunflower heads. According to the results, hybrid 7 had an unfavourable HD, while hybrid 2 had optimal. Average head diameters per treatment in 2013 were almost the same, i.e. there was no statistically significant difference between them. In 2014, irrigation decreased average HD, resulting in significant differences between treatments. In contrast, other studies have shown that the number of irrigations increases sunflower heads' diameter (RAUF *et al.*, 2012; GHOLINEZHAD *et al*., 2016).

Hectolitre mass

HM depends on the density, shape and size of the grain (POSPIŠIL and POSPIŠIL, 2013). It is a very important trait as it indicates seed quality, which affects germination and grain quality, directly influencing grain processing (KOLAK, 1994). Irrigation resulted in an increase of the HM in all hybrids and both years, which is also statistically confirmed by treatment comparison. According to the LSD test, the hybrids under investigation showed a significant variation for this trait. In 2013, hybrid 1 had the highest, i.e. optimal values in both rainfed (44.18 kg/hl) and irrigated (45.80 kg/hl) treatments, while hybrid 4 had the lowest HM in both treatments (37.83

kg/hl in rainfed and 39.40 kg/hl in irrigated). POSPIŠIL and POSPIŠIL (2013) stated that HM in sunflower plants ranges between 37 and 47 kg/hl. Conditions in 2014 had a different impact on the HM than in 2013. Hybrids with the lowest or highest HM values in rainfed did not follow the same trend in irrigated treatment, as was the case in 2013. Namely, hybrid 5 in rainfed (35.95 kg/hl) and hybrid 4 in irrigated treatment (36.28 kg/hl) had the lowest HM, while hybrid 8 in rainfed (41.98 kg/hl) and hybrid 7 in irrigated treatments (44.48 kg/hl) had the highest HM. Similar variation in different sunflower cultivars' hectolitre mass in 1999 and 2000 was reported by POSPIŠIL *et al.* (2001), who concluded that a low HM could indicate high shell content. Finally, there were statistically significant differences between hybrids in average HM values for both treatments. Hybrid 1 had the highest average HM in 2013, hybrid 7 had the highest average HM in 2014, while hybrid 4 had the lowest average HM in both years.

1000-grain weight

The TGW depends on the sunflower type, but there are also significant differences in cultivation types and environmental factors (ŠKORIĆ, 2012). The TGW is a complex quantitative trait and an important sunflower seed yield component. Knowing the TGW is the key to successful seed production because it affects the sowing rate, the density of plants during the growing season, as well as the SY per unit area (RADIĆ *et al.*, 2013). When sowing sunflowers in less favourable agro-ecological conditions, it is necessary to use seeds with higher values of TGW because plants from such seeds grow faster due to the higher content of food reserve from which they receive energy for initial growth (BALALIĆ *et al.*, 2012). Although water stress usually reduces the TGW, probably due to the reduction in water and mineral uptake by the plant and the reduction in assimilating building and transfer to seed and seed half-filling (SEGHATOLESLAMI *et al.*, 2012), this was not the case here. The average TGW per treatment was significantly higher in the rainfed treatment in both years, i.e. the grain was less filled under irrigation treatment. Irrigation decreased TGW in 2013 and 2014 by 3.99 and 3.39%, respectively. These results contradict the results obtained by RAUF *et al.* (2012) and KAYA and KOLSARICI (2011), who determined the highest values of TGW when they applied full irrigation throughout the sunflower vegetation. Hybrid 1 had the lowest TGW values in both rainfed and irrigated treatments in 2013 and 2014 (rainfed: 51.50 and 44.78 g; irrigated: 51.65 and 42.36 g, respectively), while hybrid 3 had the highest values in both rainfed and irrigated treatments in 2013 and 2014 (rainfed 76.25 and 62.59 g; irrigated: 70.78 and 60.90 g, respectively), which is also confirmed by LSD. POSPIŠIL *et al.* (2001) determined that TGW ranged from 43.5 to 70.2 g in 1999 and 33.6 to 94.2 g in 2000.

Seed yield

SY is the most important economic metric trait for crop growers (HLADNI *et al.*, 2014). It is a quantitative trait that can differ between and within hybrids, which was confirmed in this research as well. SY ranged from 3.97 (H1 in rainfed) to 5.94 t/ha (H2 in irrigated) in 2013. In 2014, the range was 2.90 (H7 in rainfed) – 4.96 t/ha (H2 in rainfed). The shown values indicate irrigation's cost-effectiveness in achieving higher sunflower yields in 2013. Hybrids significantly varied in SY in both testing years. IQRASAN *et al.* (2017) recorded yields in the range of 3904 – 4577 kg/ha, while LIOVIĆ *et al.* (2017) recorded seed yields from 5.27 to 6.95 t/ha, which confirms the existence of variability for the trait. Furthermore, a large genetic difference for SY in well-watered and water stress conditions was reported by GHOLINEZHAD *et al*. (2016). Sunflower is a climate-adaptable crop that provides satisfactory seed yields in both dry and warm weather conditions (PEPÓ and NOVÁK, 2016). Nevertheless, extreme weather conditions (dry or rainy weather) decrease the yield. Here, average SY values for treatments significantly increased with irrigation in 2013 by 6.96%, but irrigation statistically significant decreased average SY in 2014 by 3.69%. KAYA and KOLSARICI (2011) observed that sunflower vegetative growth is enhanced when irrigation is applied before the flowering phase, while irrigation applied in the flowering and late flowering phase increased the SY, which may explain higher SY in irrigation treatment in 2013 in this study. Furthermore, the amount of added water during irrigation also affects the SY (ELTARABILY *et al.,* 2020). According to SEGHATOLESLAMI *et al.* (2012), sunflower yields were 2.64 times higher in optimum irrigation treatment than in severe water deficit stress, which could also be one reason for the difference in SY in irrigated treatment between years in this study.

Oil content

Being one of the most important sunflower traits for processing and oil production, OC is strongly affected by the environment, making it difficult to predict it (BALALIĆ *et al.,* 2012; ANDRIANASOLO *et al.*, 2016). It depends on the average daily temperatures and available moisture in the grain filling phase, as well as on the duration of that phase. The accumulation of sunflower oil begins in the reproductive phase of anthers development and lasts until the plants' physiological maturity, i.e. it depends on the period's length from flowering to physiological maturity. The accumulation of oil in the seed is more successful with adequate soil moisture, average daily temperatures below 25°C and if the oil filling phase is not interrupted by a disease's appearance (ŠKORIĆ, 1989). The amount of oil in sunflower seed largely depends on the leaves' ability to maintain photosynthetic activity during grain filling (ANDRIANASOLO *et al.,* 2016). Shortening of the grain filling phase can be caused by temperatures above 34°C, which negatively affects oil accumulation seed weight and can cause an increase in shell fraction (CHIMENTI *et al.,* 2001). In this research, in 2013, significant differences were found between treatments in favour of irrigation, but in 2014 there was no significant difference between treatments for OC. It ranged from 41.69% (H5 in 2014) to 54.53% (H8 in 2013) in rainfed treatment and from 41.83% (H5 in 2014) to 54.46% (H8 in 2013) in irrigated treatment in both years. The LSD test confirmed a statistically significant difference in hybrids within treatments in both years. The ranges are similar to those determined by POSPIŠIL *et al.* (2001) but have higher values than those reported by IQRASAN *et al.* (2017), i.e. 35.8–40.2%. Lower values of OC (36–42%) were reported by HUSSAIN *et al.* (2017) as well. Although variation in OC values between hybrids existed, three-way ANOVA results indicate neither year nor treatments were statistically significant variation sources. The study of the impact of irrigation at different sunflower growth phases and development revealed a significant reduction in SY and OC when irrigation was omitted in the maturing phase (RAUF *et al.*, 2012). This is evident from higher SY and OC under irrigated treatment in 2013, most likely due to a large amount of precipitation at maturation (Figure 1). In contrast, irrigation in 2014 resulted in an SY decrease, probably due to the omission of irrigation in the maturing phase. The statistical significance of irrigation was not confirmed for OC. H5 had the lowest average OC, while H8 had the highest OC in 2013, and H7 and H8 both had the highest OC in 2014.

Oil yield

Oil yield, as a product of OC and SY, is the main goal of growing sunflowers for oil production. It largely depends on a number of plant characteristics and environmental factors that are especially important in the grain filling phase (ŠKORIĆ, 2012). The range of OY values in 2013 in rainfed treatment was 1.78 (H5) – 2.38 t/ha (H8) and 1.91 (H5) – 2.68 t/ha (H2) in irrigated treatment. In 2014, the values of OY in rainfed treatment ranged from 1.33 (H7) to 2.16 t/ha (H2) and from 1.32 (H8) to 2.07 t/ha (H2) in irrigated treatment. OY's average values in rainfed treatment were 2.05 and 1.70 t/ha in 2013 and 2014, respectively, and 2.21 and 1.63 t/ha in irrigated treatment in 2013 and 2014, respectively. Higher oil yields in 2013 compared to oil yields in 2014 were confirmed by MIJIĆ *et al.* (2017), stating that the cause of such results is a satisfactory reserve of winter moisture and not too high-temperature maxima in 2013. The average OY values in eight hybrids investigated in this study were lower than those recorded by LIOVIĆ *et al.* (2017). Temperature and solar radiation, sowing dates, and localities greatly influence oil synthesis (ECHARTE *et al.*, 2013; HILWA *et al*., 2019). IQRASAN *et al.* (2017) confirmed that the quality of sunflower oil is positively affected by available water in the soil and temperatures under spring sunflower sowing conditions. A statistically significant difference in treatment was found in both years. In 2013, the average OY was higher in irrigated treatment, but in 2014 it was higher in rainfed treatment. Average values between treatments increased by 7.8% with irrigation in 2013 and decreased by 4.80% in 2014. In contrast, daily irrigation had a statistically significant effect on sunflower OY, ranging from 797.86–1143.40 kg/ha (CARVALHO *et al.,* 2020), which is markedly lower than the OY hybrids tested here. ALIPATRA *et al.* (2019) reported the impact of irrigation 30, 60 and 80 days after sowing on the increase in OY as well. It is evident that OY was affected by the time of irrigation, i.e. omission of irrigation in the maturity phase, the same as SY and OC, which is expected as OY is a product of these two traits.

Principal component analysis (PCA)

Three principal components (PCs) were identified as statistically significant, explaining 54.92% of the data variance. The first PC (PC1) accounted for 25.16% of the data set variability and had the highest eigenvalue (4.78). Loadings contributing the most to PC1 in a positive direction were SY, OY, year 2013, TGW and HD, while PH and year 2014 contributed the most but in a negative direction. The second (PC2) and third (PC3) PCs accounted for 18.11 and 11.64% of the data's variance, with eigenvalues of 3.44 and 2.21, respectively. The largest contribution to PC2 was made by hybrid 5 and PH in a positive and OC and HM negative direction. The rainfed treatment and PH contributed the most positively to PC3, and the irrigated treatment the most negatively.

PCA confirmed ANOVA's previously proven year and hybrid effects. At the same time, a negative correlation between treatments has been proven. The arrangement of hybrids in the coordinate system also demonstrated the genetic variability of the tested sunflower hybrids. It can be concluded that hybrids 1, 7 and 8 are genetically similar to each other because they are mutually close and different from other hybrids as they are arranged opposite to the remaining five similar hybrids (H2, H3, H4, H5 and H6). Simultaneously, SY, PH, HD, TGW and OY position in the PCA biplot indicate their positive relationship. HM and OC were in a positive correlation as well (Figure 2). Positive correlations of all these traits were expected and previously confirmed by MIJIĆ *et al.* (2006), who also stated that an increase in HM results in an increase in OY, OC and SY due to established positive correlation coefficients. In this study, a positive relationship was reported only for HM and OC.

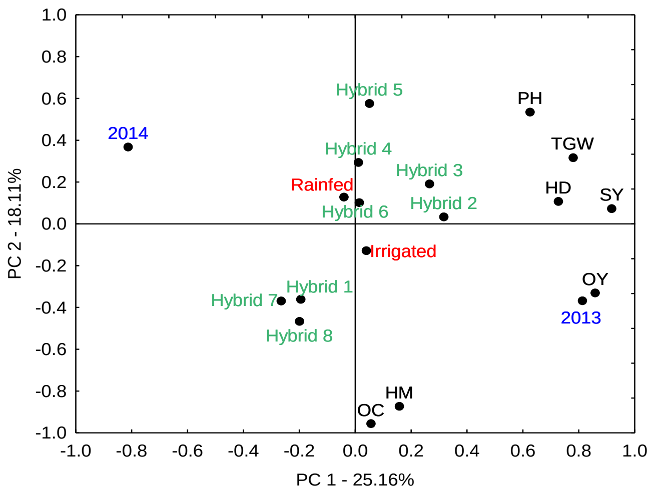

Figure 2. Biplot of principal component analysis of tested years (2013 and 2014), treatments (rainfed and irrigated) and eight sunflower hybrids (H1 – H8) for agronomic traits (PH – plant height, HD – head diameter, TGW – 1000-grain weight, HM – hectolitre mass, SY – seed yield, OC – oil content, OY – oil yield)

CONCLUSIONS

Three-way ANOVA and PCA confirmed the influence of the year on all tested agronomic traits. The significant influence of environmental conditions on the agronomic traits is evident from the significantly lower averages of all trait values determined in 2014 compared to 2013. The reason for this is the above-average precipitation amount at the time of sowing and germination, which had a negative impact on plants, causing them stress. Namely, the plants were forced to rely for a longer period on the energy stored in the seed, i.e. photosynthesis was postponed, which was reflected in the final result. The three-way ANOVA also confirmed the statistically significant effect of irrigation on PH, HM, TWG and SY. Therefore, sunflower irrigating is considered justified and can be used as an additional agrotechnical measure to target the agronomic traits. On the other hand, irrigation did not affect HD, OC, and OY, most likely due to omitting irrigation in the grain filling phase. When the years are considered separately, irrigation was not significant for HD in 2013 and PH and OC in 2014. The hybrid was a significant source of variation for all traits. ANOVA and PCA grouped the hybrids according to their similarities. Hybrids 1, 7, and 8 formed one group and hybrids 2, 3, 4, 5, and 6 formed another. The first group had lower PH, HD, TGW and SY values and higher HM, OC and OY values, and the second group had reversed traits values. Furthermore, SY was positively correlated with PH, HD, TGW and OY, and HM positively correlated with OC. This facilitates the breeding process because it enables indirect breeding for economically important traits such as seed yield, oil content and oil yield. Breeders should certainly keep in mind that most agronomic traits are expressed differently in optimal and stressful growing conditions. Understanding the expression of traits under rainfed and irrigation conditions will greatly help design effective breeding programs by creating hybrids suitable for cultivation in semi-arid environments. Although greenhouse or growth chamber research is significant for preselection, field research in real production conditions is invaluable for choosing the right genotype for the specific environment. Achieving this through breeding enables lowering of the production costs and maximising the output.

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AGRONOMSKA SVOJSTVA SUNCOKRETA U RAZLIČITIM USLOVIMA NAVODNJAVANJA U POLJU

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Izvod

Višegodišnje studije su ključne za procenu uticaja hibrida suncokreta na životnu sredinu i kvantifikovanje genetskog potencijala. Da bi se procenila adaptacija osam hibrida i ispitao uticaj dostupnosti vode na visinu biljke (PH), prečnik glave (HD), masu 1000 zrna (TWG), hektolitarsku masu (HM), prinos zrna (SY), sadržaj ulja (OC) i prinos ulja (OY), sprovedeno je dvogodišnje istraživanje sa navodnjavanjem kao tretmanom. Analizom varijanse (ANOVA) i analizom glavnih komponenti (PCA) potvrđen je uticaj godine na sva ispitana agronomska svojstva. Prema trosmernoj ANOVI, navodnjavanje je značajno uticalo na sva ispitivana svojstva osim HD, OC i OY. Istovremeno, sva agronomska svojstva imala su niže vrednosti u nenavodnjavanju i navodnjavanju u 2014. godini, što potvrđuje uticaj na životnu sredinu. Hibrid je bio značajan izvor varijabilnosti za sva svojstva. ANOVA i PCA su hibride 1, 7 i 8 grupisali u jednu grupu, a hibride 2, 3, 4, 5 i 6 u drugu. Prva grupa imala je niže vrednosti PH, HD, TGW i SY te veće vrednosti HM, OC i OY, a druga grupa je imala obrnute vrednosti. Nadalje, PCA biplot pokazuje da je SY pozitivno korelirao s PH, HD, TGW i OY, a HM je bio u pozitivnoj korelaciji s OC. To olakšava proces oplemenjivanja jer omogućava indirektno oplemenjivanje na ekonomski važna svojstava kao što su prinos semena, sadržaj ulja i prinos ulja. Budući da su tretmani bili značajan izvor varijacija za PH, HM, TWG i SY, navodnjavanje suncokreta smatra se opravdanim i može se koristiti kao dodatna agrotehnička mera za ciljna agronomskih svojstava. Razumevanje izražavanja osobina u uslovima sa i bez navodnjavanja uveliko će pomoći u dizajniranju efikasnih programa oplemenjivanja za stvaranje hibrida pogodnih za gajenje u polusušnom okruženju.

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