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Influence of Plant Density and Hybrid on Grain Yield, Oil Content and Oil Yield of Sunflower

Anto MIJIĆ[1] (✉)
Ivica LIOVIĆ[1]
Aleksandra SUDARIĆ[1]
Drena GADŽO[2]
Tomislav DUVNJAK[1]
Branimir ŠIMIĆ[1]
Danijel JUG[3]
Antonela MARKULJ KULUNDŽIĆ[1]

Summary

One necessary precondition for achieving stable and high grain and oil yields of sunflower for a certain agroecological area is the right choice of hybrids, but also the determination of the optimal plant density (number of plants per unit area) for these hybrids. Therefore, in order to determine the influence of plant density and hybrid on grain yield, oil content and oil yield of sunflower, an experiment was conducted with three plant densities (57000, 65000 and 75000 plants ha^{-1}) and 24 sunflower hybrids at the Osijek locality. The hybrid had the largest influence on the phenotypic expression of the mentioned traits, while the plant density and the plant density x hybrid interaction had a much smaller influence. On average, the highest grain yield, oil content and oil yield were achieved in the highest plant density. Hybrid H-16 had the highest grain yield (6.712 t ha^{-1}), hybrid H-11 had the highest oil content (54.89%), and hybrid H-13 had the highest oil yield (3.144 t ha^{-1}). High grain yield, oil content and oil yield of experimental sunflower hybrids indicate improvement in the breeding process at the Agricultural Institute Osijek. These hybrids can be considered as promising material in further research for the purpose of applying for recognition and commercial production.

Key words

sunflower, plant density, hybrid, grain yield, oil content, oil yield

[1] Agricultural Institute Osijek, Južno predgrađe 17, 31000 Osijek, Croatia

[2] The University of Sarajevo, Faculty of Agriculture and Food Sciences, Zmaja od Bosne 8, 71000 Sarajevo, Bosnia and Hercegovina

[3] Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences, Vladimira Preloga 1, 31000 Osijek, Croatia

✉ Corresponding author: anto.mijic@poljinos.hr

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is grown on over 26 million ha worldwide, of which about 15% in European Union countries (FAOSTAT Database, 2020). Along with palm, soybean, and oilseed rape, the sunflower is one of the most important oil production crop. Sunflower oil belongs to the highest quality oils, with high energy and biological values, so most of it is used in human nutrition and only a small part for biodiesel and industrial purposes. In addition to oil, sunflower seeds also contain a significant proportion of proteins rich in essential amino acids (methionine, cystine, tryptophan). It is an important honey plant and is also used as animal feed. From the agrotechnical point of view, it should be noted that the sunflower leaves the soil in good physical condition and usually unweeded. It also leaves the soil early and enables the timely sowing of winter crops (Gadžo et al., 2011).

Oil yield per unit area is important for every sunflower producer and is the primary goal of oil sunflower production. In realizing this trait, the values of grain yield and oil content are of great importance (Liović et al., 2012). These traits are quantitative, determined by the influence of genotype and the environment in which the genotype grows and develops and by complex genotype-environment relationships (Vratarić and Sudarić, 2004).

Each of the environmental factors (weather conditions, soil, agro-technical measures) individually and in synergy determines the investigated properties' expression to a lesser or greater extent (Šimić et al., 2008; Mijić et al., 2008, 2020; Marinković et al., 2011; Golparvar and Dehaghani, 2012; Balalić et al., 2012; Krizmanić et al., 2013; Kholghi et al., 2014; Jukić et al., 2017; Jocković et al., 2019).

Sowing, as an important agro-technical measure determines, among other things, the vegetation area of cultivated plants. This area size should ensure the most efficient reception of biofactors from soil and air, which is defined by agro-ecological conditions of the microregion of cultivation, biological characteristics of the plant (genotype), and the goal of cultivation. By defining the plant density (number of plants per unit area) i.e. vegetation space of each plant, the goal is to enable maximum utilization of biofactors from the agro-ecological cultivation area and achieve the optimal realization potential of each genotype production. The distribution of plants in the field is one of the most critical factors in determining sunflower yield and quality (Barros et al., 2004).

Based on the above, the study aimed to determine the influence of different plant densities and hybrids on grain yield, oil content and sunflower oil yield.

MATERIALS AND METHODS

The research was conducted in 2018 in Osijek (The Republic of Croatia). The plant densities were: 57000 (PD1), 65000 (PD2), and 75000 (PD3) of plants ha^{-1}. The research included 21 new experimental hybrids created within the sunflower breeding program at the Agricultural Institute Osijek and three introduced sunflower hybrids (standards 1-3) grown on large areas in the Republic of Croatia. The soil type on which the research was conducted was eutric cambisol of good pedophysical and chemical properties, with a humus content of 2 to 2.3%, well supplied with P and K and pH in KCl 6.4. The experiments were sown by hand, according to a random block design in three replications sowing depth was 5 cm. The basic plot consisted of 4 rows with 4 m in length and two inner rows were used for agronomic traits calculation. The distance between the rows was 70 cm. The fertilization was made based on chemical analysis of the soil. Herbicides were applied after sowing and before emergence (metolachlor + fluchloridone + oxyfluorfen: 1 + 1.5 + 0.5 l ha^{-1}), and fungicides in the butonization phase (boscalid + dimoxystrobin: 0.5 l ha^{-1}). The harvest was done with a plot combine harvester. The traits of grain yield, oil content, and oil yield were analyzed. The analyzed traits values were systematized by plant densities and hybrids and processed using statistical software package Statistics v.10 (StatSoft, Inc., 2011).

Weather conditions

During the sunflower vegetation (April to September), an average higher air temperature of 1.3 °C was determined compared to the multi-year average (Table 1). The warmest month was August (23.6 °C), and a lower temperature compared to the multi-year average was recorded only in July.

During the pre-vegetation period (January, February and March) in 2018, the amount of 215.3 mm of precipitation was recorded and it can be said that the winter moisture reserves were satisfactory. In the vegetation period (April to September), precipitation was by 31.3 mm less in comparison to the multi-year average, while at the same time a somewhat more pronounced deficit of precipitation was found in April, May, August and September. It should be noted that during June and July above-average rainfall was recorded.

Table 1. Mean monthly air temperature (°C), monthly precipitation (mm) and multi-year mean of temperature and amount of precipitation for Osijek

Month	Temperature		Precipitation	
	2018	Mean (2000-2019)	2018	Mean (2000-2019)
I-III	3.2	3.5	215.3	45.9
IV	16.5	12.7	21.0	48.9
V	20.1	17.3	27.4	78.9
VI	21.0	21.0	126.8	83.9
VII	22.1	22.7	131.6	62.1
VIII	23.6	22.2	36.3	65.1
IX	17.4	16.9	27.1	62.5
IV-IX	20.1*	18.8*		
IV-IX			370.2**	401.5**

*Mean; **Sum

RESULTS AND DISCUSSION

Grain yield

The analysis of variance (Table 2) showed that the phenotypic expression of the grain yield was determined by: plant density, hybrid, but also the interaction of plant density x hybrid. Only the hybrid had a statistically significant effect on grain yield.

The highest grain yield, although not statistically significant, was achieved in the highest plant density (average 5.627 t ha^{-1}), then in the smallest plant density, while the average grain yields in the middle plant density were the lowest (Table 3). Different results were given by Barros et al. (2004), who pointed out the middle plant density as the most productive.

Table 2. Analysis of variance for grain yield

Source of variation	df	SS	MS	SS (%)
Plant density (PD)	2	0.75	0.38 ^{ns}	0.7
Hybrid (H)	23	81.83	3.56**	80.1
PD x H	46	19.58	0.43 ^{ns}	19.2
Error	142			

**indicate significance at the P<0.01; ns - not significant; df - degrees of freedom; SS - sum of squares; MS - mean square

Analyzing the hybrids, it should be noted that hybrids H-16, H-13, H-8 and H-19 proved outstanding, with a grain yield greater than 6 t ha^{-1}. Also, these hybrids achieved higher grain yield values compared to all three standards.

In Table 3 we can see the variability of different hybrids in one plant density, but also one hybrid in different plant densities. The highest grain yield was achieved by the genotype H-16 in the highest plant density (7.003 t ha^{-1}) and middle (6.913 t ha^{-1}), while in the smallest plant density it had 6.219 t ha^{-1} and was third in the range. This can be explained by the fact that it is a quantitative trait, whose expression, in addition to the hybrid, was influenced by the interaction of the plant density x hybrid and slightly smaller plant density. Also, this supports the fact that each hybrid has a certain plant density in which it will achieve its optimum agronomic traits and maximize its production potential (Vratarić, 2004).

Oil content

The results of the oil content analysis of variance (Table 4) showed statistically high significant differences between plant densities and hybrids, but not for the plant density x hybrid interaction. The oil content was most influenced by the hybrid (93.3%), and less by the interaction of the plant density x hybrid and the plant density.

The highest oil content was found in the highest plant density (51.47%) and statistically significantly higher compared to middle (50.76%) and the smallest plant density (50.68%) (Table 5). Similar results were obtained by Diepenbrock et al. (2001) and Ibrahim (2012), while Ali et al. (2007) and Petcu et al. (2010) point out that the highest plant density does not give the highest oil content at the same time. In the studies of Nel et al. (2000) the plant density did not statistically significantly affect the oil content.

The highest oil content was found in the highest plant density in the experimental hybrid H-11 (55.08%), and the lowest in the same plant density in the hybrid H-21 (46.93%). Also, genotype H-11 achieved the highest oil content in middle plant density (54.63%) and the smallest plant density (54.96%).

In addition to grain yield, the oil content is an important component in the production of high-oil sunflower hybrids and in most modern sunflower hybrids ranks from 45 to 50% (Jocić et al., 2015). Đakov (1986) points out that, as a rule, oil varieties have a higher proportion of core, and Vranceanu (2000) that in a less plant density the proportion of shell is higher, which results in a lower oil content. According to Bedov (1988), oil yield is the main goal of sunflower production, and high oil content in cytoplasmic male-sterile and restorer lines is a good precondition for the creation of high-oil hybrids. Krizmanić et al. (2013) stress that in addition to the applied agro-technical measures, the oil content is also influenced by soil type, average daily temperatures and humidity.

Oil yield

The phenotypic expression of the oil yield trait was determined by: plant density, hybrid and plant density x hybrid interaction, but their influence was different. Only the hybrid had a statistically significant effect on oil yield (Table 6).

The highest oil yield was achieved in the highest plant density (2.632 t ha^{-1}), and the lowest in middle plant density (2.531 t ha^{-1}). As with the previous two traits, the variability of this trait is observed in different hybrids in one plant density, but also in one hybrid in different plant densities (Table 7). The highest oil yield was achieved by genotype H-13 in the smallest plant density (3.308 t ha^{-1}) and in middle plant density (3.172 t ha^{-1}), while in the highest plant density it had 2.953 t ha^{-1} and was fifth in the rank. The H-16 hybrid achieved the highest oil yield in the highest plant density (3.236 t ha-1), while the third ranked hybrid H-19 achieved the highest oil yield in middle plant density (3.111 t ha^{-1}). These three hybrids (H-13, H-16 and H-19) had, in all three plant densities on average, oil yield above 3 t ha^{-1}, which is statistically significantly higher in relation to standard hybrids and can therefore be considered as promising material in further research for the purpose of applying for recognition and commercial production.

The main goal of sunflower production is to obtain a high oil yield per hectare and this trait is the main indicator of the productivity of each hybrid (Jocić et al., 2015). The basis of this trait is polygenic, which means that its expression, in addition to genotype (hybrid), is more or less determined by the environment and complex genotype x environment interaction (Mijić et al., 2011). The complexity of expressiveness of this trait can explain differences in values for individual plant densities and hybrids, but also indicate the need for further research.

Based on the coefficient of variation, it can be said that the variability of grain yield and oil yield is considerably larger than the variability of oil content.

Table 3. Grain yield (t ha^{-1}) in plant densities and sunflower hybrids

Hybrid	PD1*	R**	PD2*	R	PD3*	R	Mean	R
H-1	5.482	14	5.848	10	6.197	4	5.842	5
H-2	5.271	18	6.129	7	5.231	20	5.544	16
H-3	4.832	23	4.968	19	5.519	16	5.106	20
H-4	5.488	13	5.281	13	5.293	19	5.354	18
H-5	5.826	7	5.231	14	5.860	11	5.639	12
H-6	5.730	10	5.008	18	5.928	8	5.555	15
H-7	4.906	21	4.423	23	4.612	22	4.647	23
H-8	6.077	5	6.386	4	6.603	3	6.355	3
H-9	5.321	17	5.974	8	5.547	14	5.614	13
H-10	4.931	20	4.869	21	5.079	21	4.960	21
H-11	3.924	24	3.512	24	3.723	24	3.720	24
H-12	6.040	6	5.944	9	5.541	15	5.841	6
H-13	6.674	1	6.470	2	5.987	5	6.377	2
H-14	5.761	9	5.151	15	5.498	17	5.470	17
H-15	5.559	12	6.210	5	5.637	12	5.802	9
H-16	6.219	3	6.913	1	7.003	1	6.712	1
H-17	4.869	22	4.745	22	4.429	23	4.681	22
H-18	6.424	2	5.117	17	5.882	10	5.807	8
H-19	6.089	4	6.411	3	5.974	6	6.158	4
H-20	5.383	16	5.408	11	6.671	2	5.821	7
H-21	5.451	15	6.182	6	5.436	18	5.690	11
STANDARD 1	5.668	11	5.148	16	5.956	7	5.590	14
STANDARD 2	5.810	8	5.371	12	5.903	9	5.695	10
STANDARD 3	5.222	19	4.925	20	5.550	13	5.232	19
Mean	5.540		5.484		5.627		5.551	
Min	3.924		3.512		3.723		3.720	
Max	6.674		6.913		7.003		6.712	
	PD		H		PD*H			
LSD 5%	NS		0.687		NS			

*plant densities: PD1 = 57000, PD2 = 65000, PD3 = 75000 plants ha^{-1}; **R - rank; CV = 13.29 %

Table 4. Analysis of variance for oil content

Source of variation	df	SS	MS	SS (%)
Plant density (PD)	2	27.2	13.6**	2.6
Hybrid (H)	23	980.3	42.6**	93.3
PD x H	46	42.9	0.93^{ns}	4.1
Error	142			

**indicate significance at the P<0.01; ns - not significant; df - degrees of freedom; SS - sum of squares; MS - mean square

Table 5. Oil content (%) in plant densities and sunflower hybrids

Hybrid	PD1*	R**	PD2*	R	PD3*	R	Mean	R
H-1	50.80	11	52.31	7	53.24	8	52.11	8
H-2	49.89	15	50.57	12	50.70	16	50.39	14
H-3	50.10	14	51.44	10	51.95	11	51.16	12
H-4	53.11	6	52.26	8	53.61	6	53.00	7
H-5	49.26	18	48.86	19	49.81	17	49.31	19
H-6	51.40	8	50.48	14	52.90	9	51.59	9
H-7	50.91	10	51.26	11	52.42	10	51.53	10
H-8	47.80	21	48.48	20	49.44	19	48.57	20
H-9	50.17	13	50.40	15	48.60	23	49.72	17
H-10	53.43	5	52.81	5	53.98	4	53.41	4
H-11	54.96	1	54.63	1	55.08	1	54.89	1
H-12	52.88	7	53.24	4	53.36	7	53.16	6
H-13	54.45	2	53.85	2	54.10	2	54.13	2
H-14	49.29	17	49.38	18	49.58	18	49.41	18
H-15	48.32	20	48.19	21	49.01	20	48.51	21
H-16	49.19	19	50.10	16	50.77	15	50.02	16
H-17	51.09	9	51.51	9	51.60	13	51.40	11
H-18	53.64	4	52.50	6	53.74	5	53.29	5
H-19	53.66	3	53.32	3	54.00	3	53.66	3
H-20	49.60	16	49.62	17	50.99	14	50.07	15
H-21	47.04	24	47.34	23	46.93	24	47.10	24
STANDARD 1	50.60	12	50.54	13	51.69	12	50.94	13
STANDARD 2	47.18	23	47.23	24	48.95	21	47.79	23
STANDARD 3	47.50	22	48.02	22	48.80	22	48.11	22
Mean	50.68		50.76		51.47		50.97	
Min	47.04		47.23		46.93		47.10	
Max	54.96		54.63		55.08		54.89	
	PD		H		PDxH			
LSD 5%	0.33		0.94		NS			

*plant densities: PD1 = 57000, PD2 = 65000, PD3 = 75000 plants ha^{-1}; **R - rank; CV = 1.98%

Table 6. Analysis of variance for oil yield

Source of variation	df	SS	MS	SS (%)
Plant density (PD)	2	0.40	0.20^{ns}	1.7
Hybrid (H)	23	17.69	0.77**	76.1
PD x H	46	5.15	0.11^{ns}	22.2
Error	142			

**indicate significance at the P<0.01; ns - not significant; df - degrees of freedom; SS - sum of squares; MS - mean square

Table 7. Oil yield (t ha^{-1}) in plant densities and sunflower hybrids

Hybrid	PD1*	R**	PD2*	R	PD3*	R	Mean	R
H-1	2.524	12	2.775	7	2.989	3	2.763	7
H-2	2.397	18	2.827	5	2.412	20	2.545	13
H-3	2.204	23	2.326	16	2.608	13	2.380	20
H-4	2.652	7	2.511	11	2.581	14	2.581	11
H-5	2.611	9	2.324	17	2.660	11	2.532	15
H-6	2.680	6	2.301	20	2.856	8	2.612	9
H-7	2.268	20	2.065	23	2.197	22	2.177	23
H-8	2.640	8	2.821	6	2.971	4	2.811	6
H-9	2.436	15	2.743	8	2.454	19	2.544	14
H-10	2.398	17	2.344	15	2.495	16	2.413	19
H-11	1.968	24	1.747	24	1.869	24	1.861	24
H-12	2.907	4	2.881	4	2.691	10	2.826	4
H-13	3.308	1	3.172	1	2.953	5	3.144	1
H-14	2.591	11	2.320	18	2.486	17	2.465	17
H-15	2.451	14	2.723	9	2.516	15	2.563	12
H-16	2.786	5	3.151	2	3.236	1	3.057	2
H-17	2.268	21	2.226	21	2.081	23	2.191	22
H-18	3.136	2	2.435	13	2.875	7	2.815	5
H-19	2.972	3	3.111	3	2.935	6	3.006	3
H-20	2.431	16	2.447	12	3.096	2	2.658	8
H-21	2.334	19	2.664	10	2.321	21	2.440	18
STANDARD 1	2.609	10	2.373	14	2.803	9	2.595	10
STANDARD 2	2.497	13	2.309	19	2.629	12	2.478	16
STANDARD 3	2.258	22	2.155	22	2.463	18	2.292	21
Mean	2.555		2.531		2.632		2.573	
Min	1.968		1.747		1.869		1.861	
Max	3.308		3.172		3.236		3.144	
	PD		H		PD*H			
LSD 5%	NS		0.328		NS			

*plant densities: PD1 = 57000, PD2 = 65000, PD3 = 75000 plants ha^{-1}; **R - rank; CV = 13.67 %

CONCLUSION

Based on the conducted research of the influence of plant density and hybrid on grain yield, oil content and oil yield of sunflower in field experiment with three plant densities and 24 sunflower hybrids, it can be concluded:

- the hybrid had the largest influence on the phenotypic expression of the investigated traits, while plant density and plant density x hybrid interaction had significantly lesser influence
- the highest grain yield, oil content and oil yield were achieved in the highest plant density (75000 plants ha^{-1})
- the H-11 hybrid achieved the highest oil content in all three plant densities
- experimental hybrids H-16, H13, H-8 and H-19 stood out with grain yield over 6 t ha^{-1}
- experimental hybrids H-13, H-16 and H-19 stood out by oil yield over 3 t ha^{-1}
- high grain yield, oil content and oil yield of the experimental sunflower hybrids indicate the progress in the breeding process at the Agricultural Institute Osijek, as well as the need for further research.

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