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RESEARCH ARTICLE

Agronomic performance of sunflower hybrids grown in the semi-arid climate of Romania

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ABSTRACT

The increasing demand from farmers for sunflower (*Helianthus annuus* L.) hybrids with high seed yield and high oil content requires the replacement of older hybrids with new hybrids that have improved traits and better adaptation to climate change. Multi-annual studies are essential for the evaluation of sunflower hybrids and the identification of those suitable with specific adaptations to various agro-climatic areas. Thus, to evaluate the adaptation of nine hybrids and test the impact of semi-arid conditions on seed yield, oil content, and some morphological traits, a 3-yr study was carried out in the conditions of Agricultural Research and Development Station (ARDS) Șimnic (Romania). The ANOVA results indicated the significant influence of the hybrid (H), year (Y) and the H×Y interaction on all the studied traits. Overall, the year 2020 was better for seed yield (2658.8 kg ha^{-1}) and hectolitre weight (47.9 kg hL^{-1}). On the other hand, 2021 was more efficient for oil content (46.8%), while 2022 was more efficient for plant height, head diameter and 1000-seed weight (133.5 cm, 19.8 cm, and 48.3 g, respectively). The highest seed yield was achieved by 'FD 18E41' with 1849.3 kg ha^{-1}, this could reliably be used in sunflower farming under semi-arid conditions of South-Western Romania. For other traits, the superior sunflower hybrids were: 'FD19E42' for oil content (46.5%); 'Fundulea 911' for hectolitre weight (43.5 kg hL^{-1}); 'Performer' for plant height (133.4 cm) and 1000-seed weight (55.3 g); 'Fundulea 708' for head diameter (18.8 cm).

Key words: Head diameter, hectolitre weight, *Helianthus annuus*, oil content, plant height, seed yield, 1000-seed weight.

INTRODUCTION

One of the most important oilseed crops worldwide is sunflower (*Helianthus annuus* L.), which ranked second after soybean in oil trade (import 13.4 million tons; export 12.6 million tons) and first in Europe (import 4.5 million tons; export 11.1 million tons), in 2021. In Europe, sunflower is cultivated mainly in the southern and eastern regions, covering 21.2 million ha (FAO, 2023).

Sunflower has become an important source of vegetable oil because it can be cultivated in less favourable areas, such as semi-arid, without irrigation. Also, the positive effects of sunflower seeds and oil on human health add even more value to consumer choice (Franco et al., 2018). The literature mentions that the sunflower was introduced to Europe in the 17th century, at first it was cultivated as an ornamental plant, and the cultivation of the sunflower for oil production began in 1769 (Giannini et al., 2022).

Romania was the first country in the world to obtain and introduce sunflower hybrids into the culture, namely 'Romsun 52' and 'Romsun 53' which were registered in 1971. Due to genetic advances, the Romanian sunflower hybrids created at the National Agricultural Research and Development Institute (NARDI) Fundulea have won a place on the world market, being registered for cultivation in many countries such as France, Spain, Turkey, Greece, Italy, Ukraine, Russia, Belarus, Kazakhstan, China and some African countries (NARDI, 2017). As a result of the high demand for sunflower oil, but also its various uses, many Romanian farmers use sunflower in the structure of their crops along with cereals and rapeseed. In 2021, Romania cultivated almost 1.124 million hectares, being among the largest producers of sunflower seeds in Europe (2.8 million tons), after Ukraine and the Russian Federation, but due to the reduced processing capacity, it became the largest exporter in Europe (1.4 million tons) (FAO, 2023).

Despite constant genetic advances, current climate change may limit the yield of sunflower crops, even though sunflower is considered drought tolerant. The negative effects of drought and heat on productivity vary depending on their severity, the development stage of the crop, and the tolerance of the genotype (Tabără et al., 2018). Water is essential at every stage of growth, but the productivity of the sunflower depends especially on the availability of water during the flowering-seed filling period (Ştefan, 2016; Tabără et al., 2018).

Climate models for European regions show that drought and heat will occur more often, start earlier, and last longer. As a result, yield losses will be substantial if the adaptation of cultural practices to these changes is not considered (Debaeke et al., 2017). This problem is also essential for field crops grown in various agricultural areas in Romania, especially in the stressful conditions of South-Western Romania (Oltenia region), an area frequently affected by drought and heat that sets especially in the months of summer (June-July), leading to substantial yield losses (Bonea and Urechean, 2020; Dunăreanu and Bonea, 2022). According to the European Court of Auditors (ECA Report, 2018), Romania is one of the top seven countries in Europe in terms of aridity (desertification) risks, and a recent study confirms the steep aridization trends in South-Western Romania (Pravalie et al., 2014).

Drought stress in sunflower firstly affects the morphological traits of the plant, determining the reduction of the habitus of the plants, and as a consequence, the reduction of the leaf surface, and secondly, the yield traits, namely the number of seeds per head, 1000-seed weight (Ştefan and Constantinescu, 2022). Also, temperatures higher than 30 °C during the flowering period, accompanied by drought, cause significant damage to seed production because the pollen loses its viability and thus increases the percentage of dry seeds while reducing the oil content (Ştefan, 2016).

One of the most important agricultural practices and the key to a high and stable yield is the use of cultivars with good adaptation to the weather conditions specific to each cultivation area (Yeremenko et al., 2020). Choosing the most suitable sunflower cultivars for each area offers the possibility of obtaining high yields and high quality because the soil and climate factors of the area where they are grown are of great importance in determining the seed yield and the content of oil (Gul and Coban, 2020). Due to its multiple advantages, the sunflower has been proposed as a potential crop model for adapting to a changing environment; therefore, it is essential to evaluate hybrids in various environments (Jockovic et al., 2019).

The use of the most adapted cultivars represents a low-cost input to the production system and is thus easily adopted by farmers (Arshad et al., 2013). Establishing the most appropriate breeding strategies for obtaining high-yield and high-quality cultivars depends on understanding the effects of Genotype × Environment interaction. In order to determine the agronomic performance and adaptation of cultivars to different local environmental conditions, they must be constantly evaluated, taking into account, in particular, the existence of Genotype × Environment interaction (Shigaki et al., 2019).

In this context, the present study aimed to evaluate seed yield, oil content, and other morphological traits for nine sunflower hybrids in order to choose the most suitable ones for semi-arid climate. These Romanian sunflower hybrids are mostly new, recently registered, and have not been tested before under the drought and heat conditions of this area.

MATERIALS AND METHODS

Experimental site, plant material and experimental design

Nine sunflower hybrids (seven hybrids registered after 2015) developed at the National Agricultural Research and Development Institute (NARDI) Fundulea, Romania, presented and described in Table 1, were evaluated during the period from 2020 to 2022 in the experimental field of Agricultural Research and Development Station (ARDS) Simnic (44°19' N, 23°48' E, 182 m a.s.l.; Oltenia area) characterized with semi-arid conditions. The soil was reddish preluvosol, classified as Hapludalfs (USDA Soil Taxonomy; Soil Survey Staff, 1999). The main properties of this soil at Ap (0-29 cm) and Apt (29-43 cm) surface horizons are as follows: Humus content 2.68%-2.33%; N content 0.072-0.071 mg kg^{-1}, P and K contents 52.2-32.3 and 125-104 mg kg^{-1}, mobile P 52.2-32.3 mg kg^{-1}, mobile K 125-104 mg kg^{-1} and pH (1:2.5 H_2O) 5.08-5.33 (Radu et al., 2019).

Table 1. The main characteristics of the sunflower hybrids evaluated.

Hybrid	Year of registration	Maturity group	Description
Performer	1996	Semi-late	Medium resistant to *Botrytis cinerea*, tolerance to *Sclerotinia sclerotiorum*, resistant to falling
FD 15E27	2016	Semi-late	Resistance to sulfonylurea herbicides (Express-Sun), genetic resistance to *Plasmopara halstedii*, tolerance to *Phomopsis helianthi* and *S. sclerotiorum*, tolerance to *Orobanche cumana* races F-G
FD 18E41	2019	Semi-late	Resistance to sulfonylurea herbicides (Express-Sun), genetic resistance to *P. halstedii*, tolerance to *P. helianthi*, *Phoma oleraceae* and *S. sclerotiorum*, tolerance to *O. cumana* races F-G
FD 19E42	2020	Semi-late	Resistance to sulfonylurea herbicides (Express-Sun), genetic resistance to *P. halstedii*, tolerance to *P. helianthi* and *P. oleraceae*, resistance to *O. cumana* races F-G
FD 15CL44	2016	Semi-late	Resistance to imidazolinone herbicides (Clearfield), genetic resistance to *P. halstedii* (races 304, 330, 710, 714), tolerance to *P. helianthi* and *S. sclerotiorum*, tolerance to *O. cumana* races F-G
FD 18CL58	2019	Semi-late	Resistance to imidazolinone herbicides (Clearfield), genetic resistance to *P. halstedii*, tolerance to *P. helianthi*, *P. oleraceae* and *S. sclerotiorum*, resistance to *O. cumana* race E
FD 20CL70	2021	Semi-late	Resistance to imidazolinone herbicides (Clearfield), genetic resistance to *P. halstedii*, tolerance to *P. helianthi*, *P. oleraceae* and *S. sclerotiorum*, resistance to *O. cumana* race E
Fundulea 708	2011	Semi-late	Resistant to drought and heat, good resistance to breaking and falling, resistance to *P. halstedii* and *P. helianthi*
Fundulea 911	2012	early	resistant to drought and heat, good resistance to breaking and falling, resistance to *P. halstedii*, *P. helianthi* and *S. sclerotiorum*

Plots with hybrids were arranged in a randomized block design with three replicates. Each experimental plot consisted of four rows 8 m long and measured 2.8 m × 8 m (22.4 m^2), density of plants being 57 000 plants ha^{-1}.

The data from the Craiova Meteorological Station, Romania, located in the proximity of the ARDS Simnic experimental field for the study years, are presented in Table 2. The amount of precipitation recorded in each year of experimentation was below the multiannual average (653.9 mm), while the temperatures exceeded the multiannual average (12.4 °C), except for 2021. Climatic conditions showed quite a large variability throughout the 3 yr experimentation, due to the transitions from the severe drought in June (2022) and July (2021), to the excess of precipitation in July (2020), which had significant effects on the behaviour of the hybrids evaluated.

Table 2. The sum of accumulated precipitation and average monthly temperatures from the years of experimentation at Agricultural Research and Development Station (ARDS), Șimnic.

Parameter	Year	Oct-Dec	Jan-Mar	Apr	May	Jun	Jul	Aug	Sep	Sum/average
Precipitation (mm)	2020	117.3	108.8	0	71.0	70.0	90.0	26.0	37.0	520.1
	2021	193.0	191.6	31.0	83.0	83.0	20.0	13.0	5.5	620.1
	2022	114.0	26.9	65.0	76.0	10.0	54.0	54.0	102.0	501.9
	Multi-annual average	151.8	129.8	47.8	78.5	81.5	69.2	42.7	52.7	653.9
Temperature (°C)	2020	7.8	5.9	12.0	16.2	21.3	23.2	24.5	21.4	13.3
	2021	7.1	3.7	12.3	16.4	21.2	25.5	24.7	12.6	12.1
	2022	8.9	4.0	11.5	17.7	22.8	24.7	25.1	17.4	13.2
	Multi-annual average	6.9	2.9	12.8	17.4	21.9	24.0	24.3	18.8	12.4

Agricultural practices

The same agricultural practices were applied in each year of experimentation. The preceding crop was wheat (*Triticum aestivum* L.), every year. The experimental field was ploughed in the autumn at a depth of 28 cm, and in the spring the disc harrow was used and the combiner (8-10 cm). The complex fertilizer NPK 20-20-0 was applied before sowing at a rate of 250 kg ha^{-1}, to which 150 kg ha^{-1} of ammonium nitrate (NH_4NO_3) was added in the growing season (BBCH 16-BBCH 18).

Sowing was carried out on 17 April 2020, 9 April 2021, and 5 April 2022. The herbicide *S*-metolachlor 960 g L^{-1} in a dose of 1.2 L ha^{-1} was applied before sowing. In BBCH 14-BBCH 16 stages, the herbicide quizalofop-*p*-tefuryl 40 g L^{-1} was applied at 1 L ha^{-1} to combat annual and perennial monocotyledons weeds (when the weeds have reached a height of 15-20 cm). On the BBCH 51-BBCH 53 stages, treatments with the fungicide boscalid 200 g L^{-1} + dimoxystrobin 200 g L^{-1} in a dose of 0.5 L ha^{-1} and with the insecticide thiamethoxam 250 g kg^{-1} in a dose of 0.1 kg ha^{-1} were applied. Two mechanical and one hand-hoeing were carried out. Harvests were performed with a combine on 15 September 2020, 8 September 2021 and 30 August 2022.

Data collected

The main agronomic data collected included plant height, head diameter, hectolitre weight, 1000-seed weight, and seed yield. The plant height (in BBCH 69) and the head diameter (in BBGH 87) were measured in the field on 10 plants from each plot. The 1000-seed weight was determined by counting and weighing 1000 seeds for each plot. The method used to determine the oil content was near infrared transmission (NIT) spectroscopy, and the equipment with which the determinations were made was the Mininfra SmarT Grain analyzer (Infracont, Pomáz, Hungary). Grain analyzer (AM 5200-A, Perten Instruments, Stockholm, Sweden) was used to determine the hectolitre weight and seed moisture. Seed yield was determined by harvesting whole plots, weighing, reporting per hectare and adjusting to 9% moisture.

Statistical analyses

The statistical processing of the results was done with the help of the Minitab 21.4.0 program (Minitab, State College, Pennsylvania, USA) using the ANOVA with two factors and the Fisher LSD test ($P < 0.05$). Relationships between sunflower traits were determined using Pearson's correlation coefficients.

RESULTS

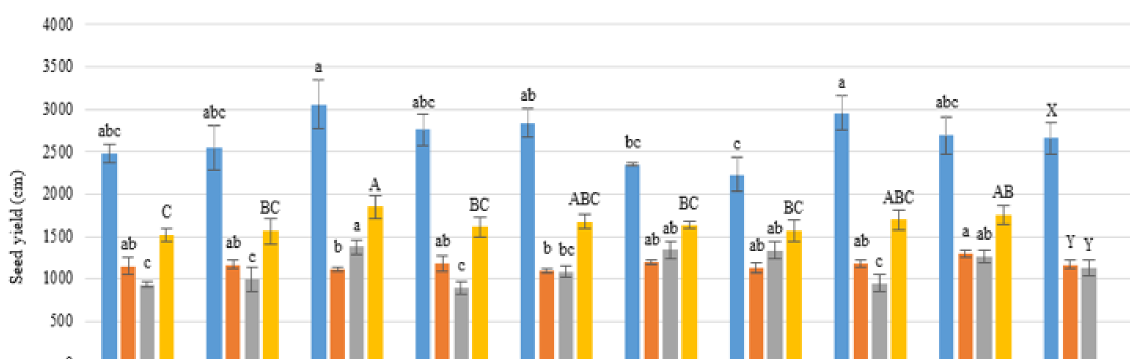
The results of the ANOVA for the studied traits showed significant differences among hybrids (H) and years (Y). Also, the H×Y interaction was significant, showing that unpredictable environmental variations (precipitation, temperature, etc.) changed the ranking of hybrids each year. The proportion of mean squares showed that the variation of all studied traits was dominated primarily by the year effect (Table 3).

Table 3. Analysis of variances (mean squares) for the seed yield and the studied traits of nine sunflower hybrids grown at Agricultural Research and Development Station (ARDS) Șimnic during 2020-2022. df: Degrees of freedom; *Significant at 0.05 probability levels.

Source of variation	df	Seed yield	Plant height	Head diameter	Hectolitre weight	1000-seed weight	Oil content
		kg ha^{-1}	cm	cm	kg hL^{-1}	g	%
Hybrid (H)	8	95856*	363.7*	27.2*	18.6*	505.1*	22.3*
Year (Y)	2	20489547*	3840*	432.2*	1393*	667.1*	321.6*
H×Y	16	131313*	314.9*	12.4*	9.6*	111.6*	18.8*
Within	54	51187	40.5	1.8	0.3	1.8	0.04

Seed yield and plant height

The data presented in Figure 1 showed that, on average, a better performance of the sunflower was in 2020 when it recorded a higher seed yield by +56% compared to 2021 and by +57.4% compared to 2022. In 2020, the seed yields obtained were between 2235 and 3059.3 kg ha^{-1}. Maximum seed yields were achieved by 'FD 18E41' (3059.3 kg ha^{-1}) and 'Fundulea 708' (2959.7 kg ha^{-1}). In 2021, 'Fundulea 911' hybrid obtained a maximum seed yield (1300.3 kg ha^{-1}). In 2022, the hybrid 'FD 18E41' obtained significantly higher seed yield (1377.3 kg ha^{-1}) followed by 'FD 18CL58' (1341.7 kg ha^{-1}), 'FD 20CL70' (1333.7 kg ha^{-1}) and 'Fundulea 911' (1266 kg ha^{-1}), compared to other hybrids.



	Performer	FD 15 E27	FD 18 E41	FD 19 E42	FD 15CL44	FD 18CL58	FD 20CL70	Fundulea 708	Fundulea 911	Mean
2020	2481.0	2541.7	3059.3	2763.0	2840.7	2351.3	2235.0	2959.7	2697.7	2658.8
2021	1151.7	1168.3	1111.3	1185.7	1096.3	1199.3	1131.0	1181.3	1300.3	1169.5
2022	933.3	992.0	1377.3	898.0	1087.0	1341.7	1333.7	951.7	1266.0	1131.2
Mean	1522.0	1567.3	1849.3	1615.6	1674.7	1630.8	1566.6	1697.6	1754.7	

Figure 1. Seed yields of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test ($P < 0.05$).

On average, over the years of experimentation, 'FD 18E41' (1849.3 kg ha^{-1}) obtained a significantly higher yield, while 'Performer' significantly lower seed yield (1522 kg ha^{-1}), compared to other hybrids (Figure 1).

The plant height, on average, was significantly higher in 2022 (+16.4%) and 2020 (+14.6%) compared to 2021 (Figure 2). In 2020, 'Performer' (146.7 cm), 'FD 15CL44' (143.7 cm), 'FD 15E27' (141 cm) and 'FD 18E41' (139.3 cm) had significantly higher values, while the hybrid 'FD 18CL58' (114 cm) had significantly lower value. In 2021, the 'FD 19E42' hybrid (122 cm) had a significantly higher plant height, while 'FD 18E41' (106.3 cm) and 'FD 20CL70' (102 cm) had significantly smaller plant heights. In 2022, the hybrid ‘Fundulea 911’ (157 cm) had a significantly higher plant height, while ‘FD 18E41’ (118.3 cm) had a significantly smaller plant height, compared to other hybrids.

On average, over the years of experimentation, significantly higher values were recorded for the ‘Performer’ (133.4 cm) and ‘FD 15CL44’ (132.7 cm) hybrids followed by ‘Fundulea 911’ (130.8), while a significantly lower value for the ‘FD 20CL70’ hybrid (113.6 cm) (Figure 2).

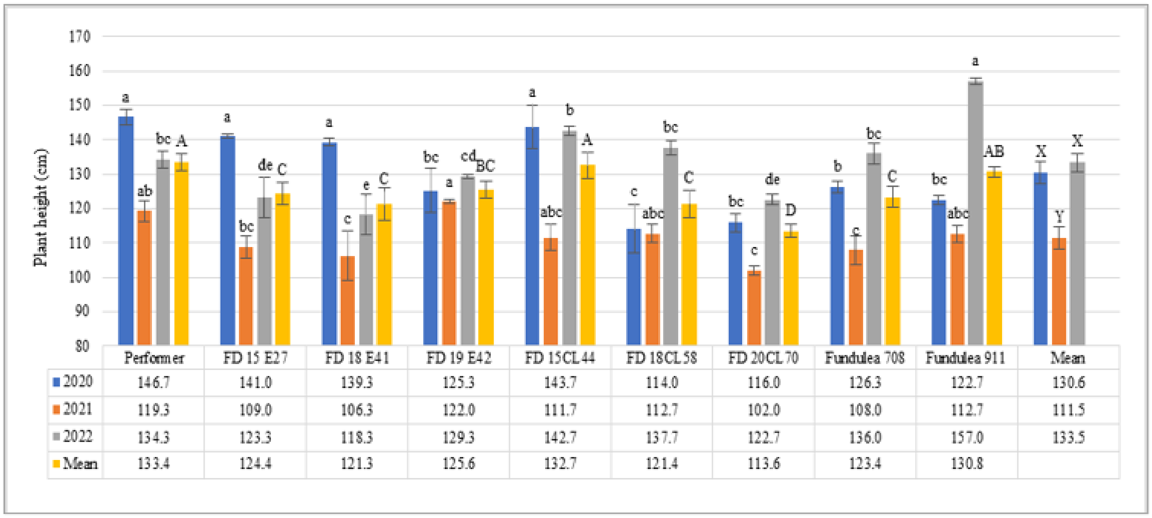


Figure 2. Plant height of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test ($P < 0.05$).

Head diameter and hectolitre weight

For the head diameter, the average value in 2022 was significantly higher by +21.2% compared to 2020 and by +40.4% compared to 2021 (Figure 3). In 2020, five hybrids: ‘Performer’ (17.3 cm), ‘FD 15CL44’ (17.3 cm), ‘FD 18 E41’ (17 cm), ‘Fundulea 708’ (17 cm) and ‘Fundulea 911’ (16.7 cm) recorded significantly higher values, while the ‘FD 20CL70’ hybrid (11.7 cm) recorded the lowest value, compared to other hybrids. In 2021, the head diameter ranged between 9.7 and 13.3 cm, without significant differences between hybrids, with a maximum head diameter achieved by ‘FD 18E41’ (13.3 cm). In 2022, ‘Fundulea 708’ (26.3 cm) recorded the highest and most significant value for the head diameter, while ‘FD 19E42’ (15 cm) had the lowest value.

On average, over the years of experimentation, significantly higher values were recorded by ‘Fundulea 708’ (18.8 cm) followed by ‘Fundulea 911’ (17.3 cm) and ‘FD 15CL44’ (16.8 cm), while the lowest value was recorded by the hybrid ‘FD 19E42’ (13.6 cm) (Figure 3).

Regarding the hectolitre weight, in 2020 it had a significantly higher average value, by +20% compared to 2021 and by +29.4% compared to 2022 (Figure 4). In 2020, the hybrid ‘Fundulea 911’ (50.8 kg hL^{-1}) had a significantly higher hectolitre weight, while ‘FD 15CL44’ (45.5 kg hL^{-1}) had a significantly lower hectolitre weight compared to other hybrids. In 2021, the hybrids ‘FD 19E42’ (40.2 kg hL^{-1}) and ‘Fundulea 911’ (39.9 kg hL^{-1}) had significantly higher hectolitre weights, while ‘FD 18CL58’ (36.7 kg hL^{-1}) and ‘Performer’ (36.4 kg hL^{-1}) had significantly lower hectolitre weights. In 2022, the hybrid ‘Fundulea 911’ stood out (39.7 kg hL^{-1}) through a significantly higher hectolitre weight, while ‘FD 19E42’ (29.3 kg hL^{-1}) had significantly lower hectolitre weight.

On average, over the years of experimentation, a significantly higher value was recorded by the ‘Fundulea 911’ hybrid (43.5 kg hL^{-1}), while a significantly lower value was recorded by ‘FD 15CL44’ (38.3 kg hL^{-1}) (Figure 4).

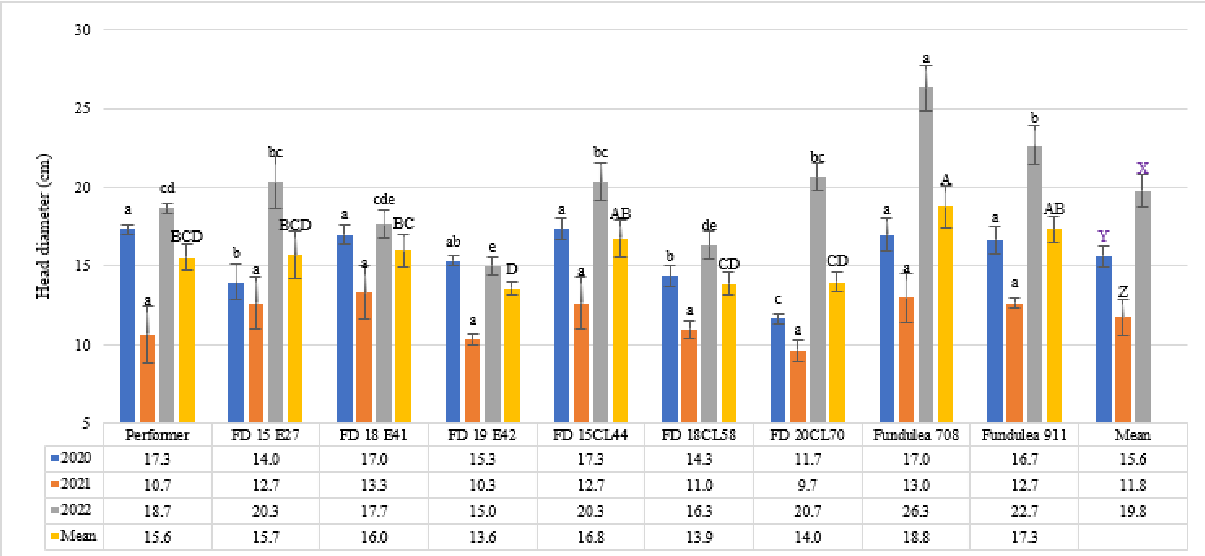


Figure 3. Head diameter of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test (P < 0.05).

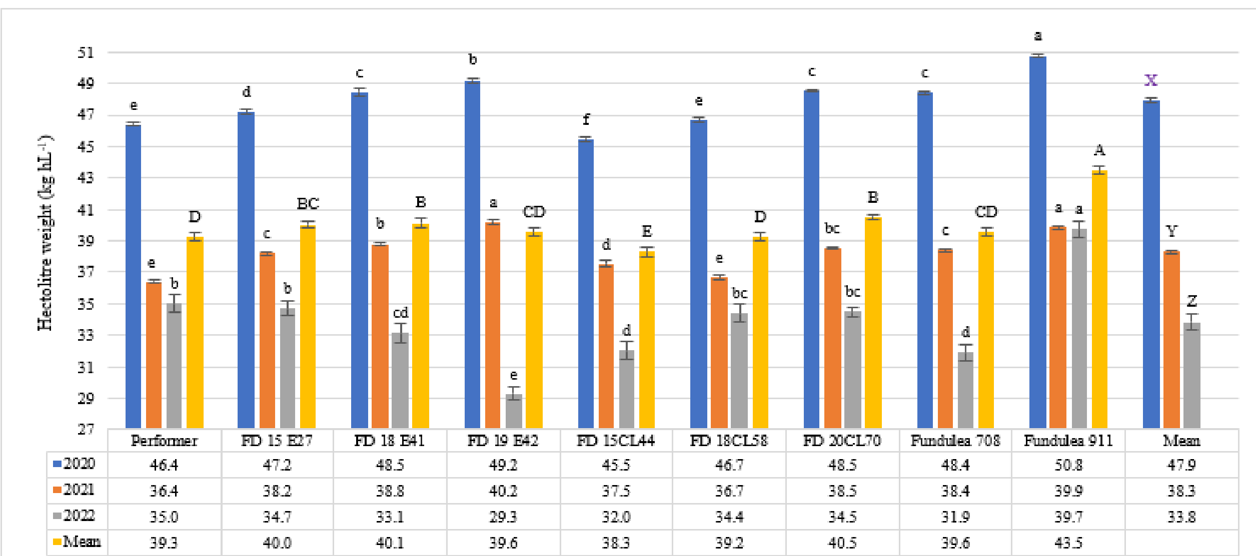


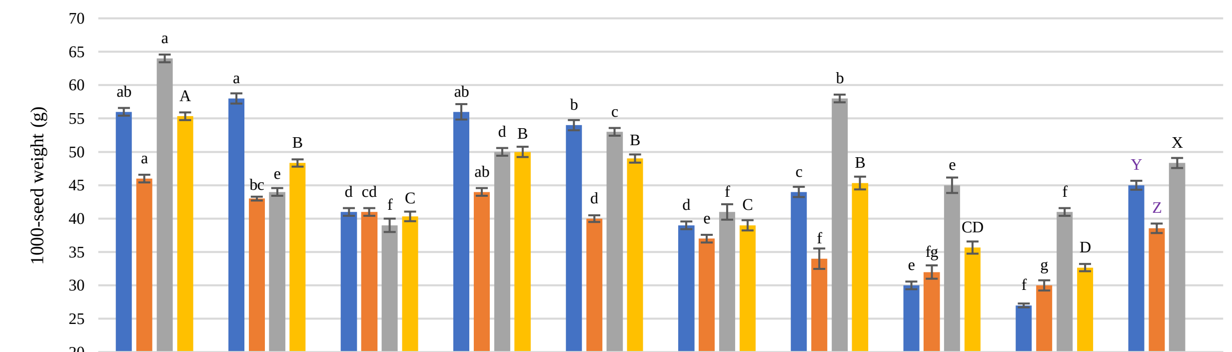
Figure 4. Hectolitre weight of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test (P < 0.05).

1000-seed weight

The average value of 1000-seed weight was significantly higher in 2022, by +20% compared to 2020 and by +29.4% compared to 2021 (Figure 5). In 2020, the highest and most significant 1000-seed weight had 'FD 15E27' (58 g) followed by 'Performer' (56 g) and 'FD 19E42' (56 g), while the smallest value had by hybrid 'Fundulea 911' (27 g). In 2021, the hybrids 'Performer' (46 g) followed by 'FD 19E42' (44 g) had the highest and most significant 1000-seed weights, while 'Fundulea 911' had the lowest value (30 g). In

2022, ‘Performer’ (64 g) had a significantly higher 1000-seed weight, while ‘FD 18CL58’ (41 g), ‘Fundulea 911’ (41 g) and ‘FD 18 E41’ (39 g) had the lowest values compared to other hybrids.

On average, over the years of experimentation, a significantly higher 1000-seed weight was recorded by the ‘Performer’ hybrid (55.3 g), while the lowest was recorded by ‘Fundulea 911’ (32.7 g) (Figure 5).



	Performer	FD 15 E27	FD 18 E41	FD 19 E42	FD 15CL44	FD 18CL58	FD 20CL70	Fundulea 708	Fundulea 911	Mean
2020	56	58	41	56	54	39	44	30	27	45.0
2021	46	43	41	44	40	37	34	32	30	38.6
2022	64	44	39	50	53	41	58	45	41	48.3
Mean	55.3	48.3	40.3	50.0	49.0	39.0	45.3	35.7	32.7	

Figure 5. 1000-seed weight of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test ($P < 0.05$).

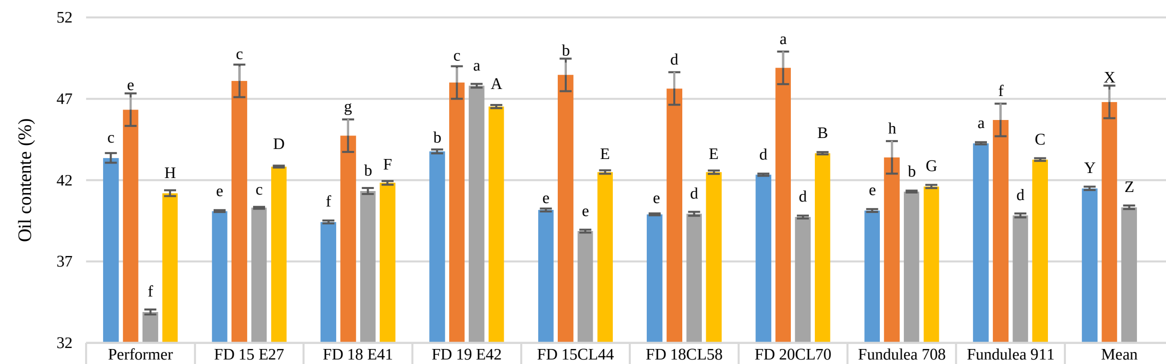
Oil content

The highest oil content was obtained in 2021, by +11.3% compared to 2020 and by 13.9% compared to 2022 (Figure 6). In 2020, ‘Fundulea 911’ hybrid (44.3%); in 2021 ‘FD 20CL70’ hybrid (48.9%); in 2022, ‘FD 19E42’ hybrid (47.8%) recorded the highest and most significant oil contents compared to other hybrids.

On average, over the years of experimentation, the significantly higher oil content was recorded in the ‘FD 19E42’ hybrid (46.5%), while the lowest oil content was recorded in the ‘Performer’ hybrid (41.2%) (Figure 6).

Correlations between studied traits

The results obtained in terms of correlation coefficients showed that seed yield was significantly positively correlated with plant height ($r = 0.27^*$; $p \leq 0.05$) and hectolitre weight ($r = 0.87^{**}$; $p \leq 0.01$), and significantly negatively correlated with the oil content ($r = -0.26^*$; $p \leq 0.05$) (Figure 7). Also, plant height was significantly positively correlated with head diameter ($r = 0.61^{**}$; $p \leq 0.01$) and 1000-seed weight ($r = 0.47^{**}$; $p \leq 0.01$), but significantly negatively correlated with oil content ($r = -0.56^{**}$; $p \leq 0.01$). The head diameter was significantly positively correlated with 1000-seed weight ($r = 0.29^{**}$; $p \leq 0.01$) and significantly negatively with oil content ($r = -0.63^{**}$; $p \leq 0.01$). Also, 1000-seed weight was significantly negatively correlated with oil content ($r = -0.40^{**}$; $p \leq 0.01$). Other correlations were small and nonsignificant (Figure 7).



	Performer	FD 15 E27	FD 18 E41	FD 19 E42	FD 15CL44	FD 18CL58	FD 20CL70	Fundulea 708	Fundulea 911	Mean
2020	43.4	40.1	39.4	43.8	40.2	39.9	42.3	40.1	44.3	41.5
2021	46.3	48.1	44.7	48.0	48.5	47.6	48.9	43.4	45.7	46.8
2022	33.9	40.3	41.3	47.8	38.9	39.9	39.7	41.3	39.8	40.3
Mean	41.2	42.8	41.8	46.5	42.5	42.5	43.7	41.6	43.3	

Figure 6. The oil content of sunflower hybrids. Bars represent standard error. Different lowercase letters indicate differences between hybrids for each year and different uppercase letters indicate differences between hybrids for the 3 yr mean, by Fisher LSD test (P < 0.05).

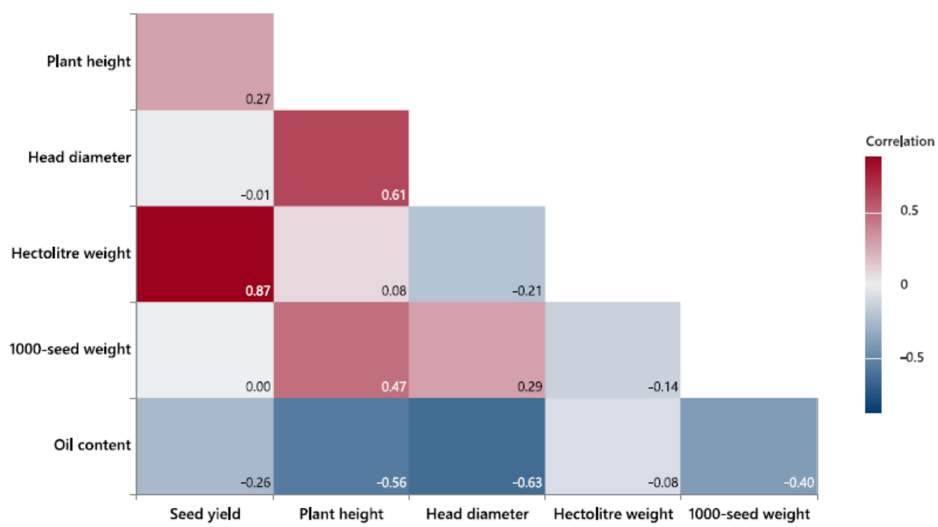


Figure 7. Correlogram of traits analysed (critical values for correlation coefficients: α = 0.05, p-value = 0.22; α = 0.01, p-value = 0.29; n = 81).

DISCUSSION

The effects of climate change on the growth and development of plants are well-known worldwide. In our study, nine sunflower hybrids (most of them being recently registered) were evaluated during three growing seasons to verify their main morpho-agronomic traits in the semi-arid conditions of southwestern Romania. In general, all the hybrids were found to be adapted for the drought and heat conditions of this area.

ANOVA results showed that hybrid, year and H×Y interaction effects were significant for seed yield. These results suggest that unpredictable environmental variations (precipitation, temperature, etc.) changed the ranking of the hybrids every year. Year was the dominant factor in seed yield variation. Contrary to these results, Gul and Coban (2020) reported that seed yield was significantly and predominantly influenced by genotype. The reduced amounts of precipitation and temperatures above the multiannual average in June and July 2021 and 2022, months that coincided with the stages of flowering and seed-filling, contributed to the decrease in the productivity of the hybrids and the obtaining of significantly lower seed yields compared to the seed yields in 2020. These results are in accordance with those reported by Öztürk (2021), who show that low water availability during the flowering and seed-filling stages can significantly reduce seed yield due to high transpiration requirements. Also, increasing temperatures above 20 °C during the flowering stage and above 22 °C during the seed-filling stage can lead to a decrease in seed yield (Ştefan, 2016). The average yields from the experimental plots were 2658.8 kg ha^{-1} in 2020; 1169.5 kg ha^{-1} in 2021, and 1131.2 kg ha^{-1} in 2022 being close to the average national yields of Romania reported by NIS (2023), which were 2530 kg ha^{-1} in 2020; 1921 kg ha^{-1} in 2021 and 1883 kg ha^{-1} in 2022. There are several factors that influence sunflower seed yield, namely environmental conditions, agricultural practices, plant genetics, and morphological, physiological, and biochemical factors (Öztürk, 2021; Vician et al., 2022).

Like other studied traits of this study, plant height was significantly influenced by all three sources of variation (genotype, year, and their interaction), but the year was the dominant factor. This finding has also been reported by Shigaki et al. (2019) and Duca et al. (2022), who showed that plant height is determined to a greater extent by climatic conditions than by genotype. Plant height is known to be an important trait for mechanized agriculture (Shigaki et al., 2019). To obtain high yields and increase resistance to falling, it is necessary to use cultivars with a plant height of 120-150 cm (Ćirić et al., 2013). In our study, the average plant height ranged from 113.6 to 133.4 cm, with most hybrids falling within the mentioned limits. In general, plant height varies depending on plant genetics, environmental conditions, and cultural practices (Bonea et al., 2013; Tabără et al., 2018; Borleanu and Bonea, 2020; Gul and Coban, 2020; Öztürk, 2021).

Regarding the head diameter, it was significantly influenced by all sources of variation (genotype, year, and their interaction), the dominant being the year. Similar results were reported by Kulundžić-Markulj et al. (2022), who observed that this trait was dominantly determined by climatic conditions. On average, the head diameter for the evaluated hybrids ranged from 13.6 to 18.8 cm. The head diameter of a sunflower may vary based on several factors including environmental conditions, cultural practices, and plant genetics (Bonea et al., 2013; Tabără et al., 2018; Gul and Coban, 2020). Öztürk (2021) found that increasing head diameters above 16 cm resulted in better yields.

For 1000-seed weight, all sources of variation (genotype, year, and their interaction) were significant, with the year being the dominant factor. Similar results were reported in previous studies by Tabără et al. (2018) and Shigaki et al. (2019), confirming that DM accumulation in seeds depends especially on the weather conditions during the growing season. The highest 1000-seed weight was obtained in the driest year 2022. This result is in accordance with that reported by Ştefan (2016), who observed that high temperatures in the flowering stage negatively affected pollination by reducing the number of seeds, but these newly formed seeds developed better with more head space and less competition for necessary nutrients. The average 1000-seed weight of the evaluated hybrids ranged from 32.7 to 55.3 g. Previous researchers reported that 1000-seed weight may vary based on environmental conditions and genotypes (Bonea et al., 2013; Alem et al., 2016; Tabără et al., 2018; Öztürk, 2021).

Hectolitre weight is a measure of bulk density, being a trait of great importance for storage and transport. In our study, all sources of variation (genotype, year, and their interaction) significantly influenced hectolitre weight, the dominant factor being the year, which was in accordance with the results obtained by Kulundžić-Markulj et al. (2022) who observed that there was a dominant effect of the year (climatic conditions). The lowest values were obtained in the dry year 2022. This result is in agreement with that obtained by Ozturk et al. (2022) who found that drought during the grain-filling period reduces hectolitre weight by increasing the rate of weak and broken grains and decreasing seed size. Another cause of the hectolitre weight reduction could be a large amount of precipitation in August 2022, confirming the results of Lollato et al. (2015) who reported that due to the rains after the grains have reached physiological maturity, the wetting and drying of the mature grains takes place and implicitly the decrease of the hectolitre weight. The evaluated hybrids had, on average, a hectolitre weight of 40 kg hL^{-1}, the limits of variation being from 32.7 to 55.3 kg hL^{-1}.

The hectolitre weight may vary depending on plant genetics and environmental conditions (Bonea et al., 2013; Tabără et al., 2018).

Oil content is another important trait that was influenced by all sources of variation, especially by year, these results being in agreement with those reported by Gul and Coban (2020) and Vician et al. (2022). For the oil content, the highest values were obtained in 2021, and this result can be explained by the fact that in this year the lowest values were obtained for the 1000-seeds weight. This result was in agreement with Mijić et al. (2017), who reported that a lower seed weight means higher oil content because smaller seeds have less shell and endosperm in relation to the nucleus. Although oil content is not a grading factor for sunflower seed quality, some sunflower seed processing companies offer bonuses for lots with oil content above 40%, penalizing those with a lower content (Dalchiavon et al., 2016). In our study, the average oil content ranged from 41.2% to 46.5%, exceeding the limit of 40%. Previous studies have reported that oil content can vary largely based on genotypes and environmental conditions (Öztürk, 2021; Vician et al., 2022).

The correlation analysis between the studied traits showed that seed yield was significantly positively correlated with only two traits, namely plant height and hectolitre weight. These results suggest that selection based on these traits could improve sunflower seed yield. On the other hand, seed yield was significantly negatively correlated with oil content, suggesting that increased seed oil content would decrease sunflower yield. In other studies, similar correlations of seed yield with hectolitre weight (Bonea et al., 2013) and plant height (Demir, 2020) were found, as well as a significantly negative association of seed yield with oil content (Arshad et al., 2013). The results of our study are not in agreement with Öztürk (2021) and Radić et al. (2021) who reported significant and positive correlations between seed yield, head diameter and 1000-seed weight. Also, Radić et al. (2013) reported a significant positive correlation between seed yield and oil content, which disagreed with our results. This discordance between results may be associated with the different influence of genotype, environment and G×E interaction on these traits.

CONCLUSIONS

Due to its low inputs (water, fertilizers and pesticides), drought tolerance and good plasticity, the sunflower is considered a model crop for adapting to new climate changes. Thus, Romanian farmers prefer this culture compared to other alternatives, but the future of this culture depends on the choice of the most suitable hybrids as well as on the attractiveness potential for farmers (price, demand on the foreign and local market).

The results of our study showed that the year (distribution and amount of precipitation, as well as average temperatures) had a dominant effect on the variation of all the studied traits. Overall, the year 2020 was better for seed yield (2658.8 kg ha^{-1}) and hectolitre weight (47.9 kg hL^{-1}). On the other hand, the year 2021 was more efficient for oil content (46.8%), and the year 2022 was more efficient for plant height, head diameter and 1000-seed weight (133.5 cm, 19.8 cm, and 48.3 g, respectively).

The highest seed yield was achieved by the FD 18E41 hybrid with 1849.3 kg ha^{-1}, this could reliably be used in sunflower farming under semi-arid conditions of South-Western Romania. For other traits, the superior sunflower hybrids were: ‘FD 19E42’ for oil content (46.5%); ‘Fundulea 911’ for hectolitre weight (43.5 kg hL^{-1}); ‘Performer’ for plant height (133.4 cm) and 1000-seed weight (55.3 g); ‘Fundulea 708’ for head diameter (18.8 cm).

Correlation’s analysis showed that seed yield depended on hectolitre weight and plant height, and these traits could be used as suitable selection criteria in the breeding program to improving seed yield in sunflower.

In general, the evaluated hybrids showed a good adaptability to the semi-arid conditions of southwestern Romania, being able to offer different opportunities for the food industry. Further research is needed to identify new hybrids with superior morpho-agronomic traits to optimize sunflower production in the study area.

Author contribution

Conceptualization: E.C., D.B. Methodology: I.C.D., D.B. Software and statistical analyses: M.B. Validation: L.A.O. Formal analysis: S.N., L.A.O. Investigation: I.C.D., D.B. Writing-original draft preparation: D.B. Writing-review and editing: E.C., M.B., D.B. Visualization: E.C., I.S. Supervision: M.B. All co-authors reviewed the final version and approved the manuscript before submission.

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