

INFLUENCE OF DROUGHT ON SEED OIL CONTENT OF SOME SUNFLOWER HYBRIDS IN YEARS 2024 AND 2025, IN SOUTH-EASTERN OF ROMANIA

Florin Gabriel ANTON¹, Maria JOÎTA-PĂCUREANU^{1,2}, Laura CONTESCU¹,
Mihaela CERGAN¹, Sabina PINTILIA¹, Marius BORDEI¹

¹National Agricultural Research and Development Institute Fundulea,
1 Nicolae Titulescu Street, Calarasi County, Fundulea, Romania

²Romanian Academy, Center of Study and Research for Agroforestry Biodiversity “Acad. David
Davidescu”, 13 Calea 13 Septembrie, District 5, 050711, Bucharest, Romania

Corresponding author email: gabi22mai@yahoo.com

Abstract

Drought is most restrictive abiotic factor who affect negatively seed yield and seed oil content of sunflower genotypes. Years 2024 and 2025 are characterized as a drought year and in this paper, we present results about seed oil content of ten sunflower hybrids belonging to NARDI Fundulea, cultivated in Express Sun system, in south eastern of Romania, in Fundulea location. In year 2024 was registered an average seed oil content between 35.2% at sunflower hybrid H8E and 45.8% at sunflower hybrid FD15E27. In year 2025 was registered an average seed oil content between 31.58% at sunflower hybrid H8E and 41.71% at sunflower hybrid FD15E27. In year 2025, was registered a lowest seed oil content at all ten sunflower hybrids analysed in both years. In year 2024 was registered an average seed yield between 623kg/ha at sunflower hybrid H8E and 1155 kg/ha at sunflower hybrid H1E. In year 2025 was registered an average seed yield between 1792 kg/ha at sunflower hybrid H2E and 2334 kg/ha at sunflower hybrid H1E. In year 2024, was registered a lowest seed yield than year 2025.

Key words: sunflower, seed oil content, drought.

INTRODUCTION

At the European Union level, Romania has consistently ranked among the leading sunflower seed producers in recent years (Panzaru et al., 2023; Voicila, 2024). In 2024, Romania occupied the first position within the European Union regarding sunflower cultivated area, accounting for 1,243.25 thousand hectares out of the total 4,791.22 thousand hectares cultivated at the EU level. A similar trend was maintained in 2025, when Romania cultivated 1,205.13 thousand hectares out of the 4,671.16 thousand hectares recorded across the European Union (EUROSTAT, 2026). In 2025, the European Union ranked third globally in sunflower seed production, with a total output of 8.58 million metric tons, following Russia and Ukraine (Table 1) (FAS USDA, 2026). Furthermore, the average sunflower seed yield within the European Union reached 1.7423 t/ha in 2024, representing the lowest value recorded during

the last nine years, while in 2025 the average yield slightly increased to 1.867 t/ha (FAS USDA, 2026).

Agro-meteorological conditions play a major role in determining the potential productivity of agricultural crops through their effects on plant growth and development (Georgieva et al., 2024; Alf et al., 2026). Environmental stress factors, particularly drought and high temperatures, may reduce seed yield, decrease seed oil content, and negatively affect pollen viability (Domenco et al., 2023; Duca et al., 2022; Ma'ali et al., 2024; Momna et al., 2023; Syed et al., 2025).

The novelty of this study consists in the comparative evaluation of 10 experimental ExpressSun sunflower hybrids under the climatic conditions specific to southeastern Romania, with emphasis on flowering dynamics, seed productivity, and oil content. Moreover, the study provides updated information regarding hybrid performance under increasingly variable climatic conditions.

Another important aspect of novelty is the assessment of hybrid adaptability under contrasting agro-meteorological conditions recorded during the experimental period. The selected hybrids differ in maturity group, productivity potential, and adaptability to abiotic stress conditions, allowing a comparative evaluation of their agronomic performance.

Table 1. Sunflower seed production worldwide in 2025

Country	Share of global production (%)	Total production (Metric tons)
Russia	33%	17 Million
Ukraine	20%	10.5 Million
European Union	16%	8.58 Million
Argentina	11%	5.5 Million
Kazakhstan	5%	2.4 Million
China	4%	2.1 Million
Turkey	3%	1.37 Million
United States	2%	1.05 Million
Moldova	2%	850,000
South Africa	1%	720,000

Source: <https://www.fas.usda.gov/data/production/2224000>

The objective of the present study was to evaluate the performance of several ExpressSun sunflower hybrids cultivated under the environmental conditions of southeastern Romania, with particular emphasis on flowering time, seed yield, and oil content. The study also aimed to identify differences among sunflower hybrids in their response to climatic conditions during the vegetation period.

MATERIALS AND METHODS

During the years 2024 and 2025, eleven sunflower hybrids were cultivated, including the check hybrid FD15E27 and ten experimental hybrids (H1E–H10E), developed by the National Agricultural Research and Development Institute Fundulea.

The experiment was arranged in a randomized complete block design with three replications. Each experimental plot consisted of four rows, 6 m in length, spaced 70 cm apart, resulting in a plot area of 16.8 m². The plant density was 55,000 plants/ha under non-irrigated conditions, using the ExpressSun production system, in the southeastern region of Romania, at the Fundulea experimental field on a cambic cernozem soil type. The sowing date was April 5, 2024, and April 25, 2025.

At the four true leaf stage, all sunflower hybrids grown under the ExpressSun system

were sprayed with an herbicide containing tribenuron-methyl at a rate of 35 g/ha for weed control.

Flowering time was recorded when 75% of the plants reached the flowering stage, in order to evaluate differences among the sunflower hybrids.

Seed oil content was determined using an MQC+ Oilseed Analyser employing nuclear magnetic resonance (NMR) technology (Oxford Instruments). Sunflower seed samples were placed in 10 mL glass cylinders, weighed, and subsequently analysed with the MQC+ NMR analyser to determine seed oil content.

Statistical software used for data analysis was MSTAT-C and statistical interpretation was performed according to Snedecor (1956).

RESULTS AND DISCUSSIONS

The total annual rainfall recorded at Fundulea in 2024 (437.0 mm) and 2025 (450.2 mm) was considerably lower than the 60-year average of 584.3 mm, indicating drought conditions during the sunflower growing seasons in Romania (Figure 1).

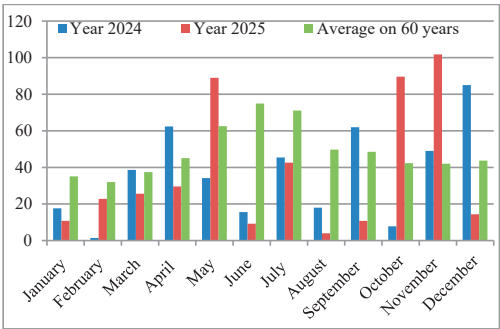


Figure 1. Average monthly rainfalls registered in Fundulea, in 2024 and 2025

For establishing the sunflower crop in April, in Romania, the water reserve accumulated during the October–March period is very important. At the Fundulea location, precipitation accumulated during the October–March period preceding sunflower establishment was below the long term average in both experimental years. Total rainfall reached 196.6 mm during October 2023–March 2024 and 201.0 mm during October 2024–March 2025, compared with the 60 year average of 232.5 mm.

Total rainfall during the sunflower growing season (April-September) was substantially lower in 2024 (237.6 mm) and 2025 (185.2 mm) than the 60-year average of 351.8 mm, confirming the occurrence of severe drought conditions during the vegetation period. Compared with the 60 year average, monthly temperatures in Fundulea during 2024 and 2025 were consistently higher, with the greatest deviations occurring in June and July, coinciding with the flowering stage of sunflower hybrids (Figure 2).

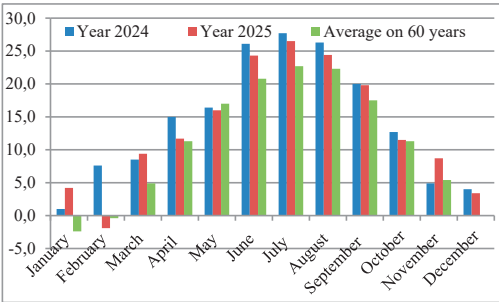


Figure 2. Average monthly temperatures (°C) registered in Fundulea, in 2024 and 2025

The average annual air temperatures recorded in 2024 (14.2°C) and 2025 (13.2°C) were considerably higher than the 60-year average of 10.9°C, reflecting the occurrence of unusually warm climatic conditions during the study period.

The combined occurrence of below average precipitation, elevated temperatures, and reduced relative humidity created drought stress conditions during the critical reproductive stages of sunflower development. Rainfall amounts during both the cold season (October-March), important for soil water reserve accumulation, and the vegetation period (April-September) were substantially lower than the long-term average. Air temperatures exceeded the multiannual average, especially during June and July, corresponding to the flowering and pollination stages of sunflower hybrids.

Average relative air humidity recorded at the Fundulea location during 2024 and 2025 were lower than the 60-year average, especially during the months of June and July (Figure 3).

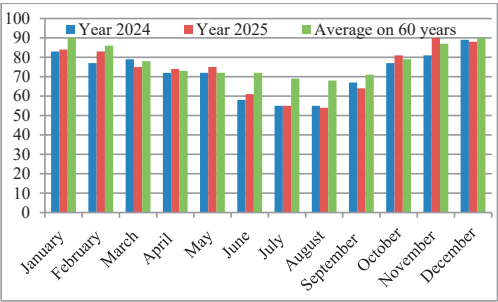


Figure 3. Average relative humidity of the air (%) registered in Fundulea location, in 2024 and 2025

The combination of reduced rainfall, high temperatures, and lower relative air humidity likely intensified evapotranspiration and drought stress conditions, negatively affecting physiological processes involved in flowering, pollination, seed formation, and oil accumulation. These climatic conditions created a favorable framework for evaluating the adaptability and performance of sunflower hybrids under drought and heat stress conditions.

The analysed sunflower hybrids exhibited differences in the number of days from sowing to flowering between the two experimental years (Table 2).

Table 2. Flowering time and number of days from sowing to flowering of sunflower hybrids evaluated at the Fundulea location in 2024 and 2025

Sunflower hybrid	Flowering time in 2024	Days from sowing to flowering in 2024	Flowering time in 2025	Days from sowing to flowering in 2025
FD15E27 check	June 23	79	July 06	72
H1E	June 24	80	July 06	72
H2E	June 24	80	July 05	71
H3E	June 24	80	July 06	72
H4E	June 24	80	July 07	73
H5E	June 25	81	July 05	71
H6E	June 26	82	July 06	72
H7E	June 24	80	July 08	74
H8E	June 23	79	July 07	73
H9E	June 23	79	July 06	72
H10E	June 25	81	July 04	70
Average	-	80	-	72

The earlier flowering observed in 2025 was associated with the higher air temperatures and drought conditions recorded during the vegetation period, which accelerated the phenological development of sunflower plants.

The reduced seed yield recorded during the experimental period (Table 3) was strongly associated with drought and heat stress conditions occurring during the critical phenological stages of sunflower development, particularly flowering and grain filling. Water deficit and elevated temperatures negatively affect photosynthetic activity, assimilate translocation, and pollen viability, leading to reduced fertilization efficiency and lower seed formation.

Table 3. Average seed yield (kg/ ha) of sunflower hybrids evaluated at the Fundulea location in 2024 and 2025

Sunflower hybrid	Average seed yield (kg/ha) in 2024	Average seed yield (kg/ha) in 2025	Average by hybrid
FD15E27	715	2277	1496
H1E	1155	2334	1744
H2E	979	1792	1385
H3E	1069	2138	1603
H4E	1067	2294	1680
H5E	971	2238	1604
H6E	904	2233	1568
H7E	897	2082	1489
H8E	623	1999	1311
H9E	939	2238	1588
H10E	985	2214	1599
Average by year	937	2167	1552

Analysis of variance (ANOVA) for seed yield (kg/ha) of sunflower hybrids cultivated at the Fundulea location during 2024 and 2025 (Table 4), indicated that Factor A (year) significantly

influenced seed yield. Tukey test confirmed significant differences significantly at $p < 0.05$, in seed yield between the two experimental years. Average seed yield in 2025 was substantially higher than in 2024 with 1776 kg/ha. The markedly reduced productivity recorded in 2024 was associated with severe drought and elevated temperatures during flowering and seed filling stages, which negatively affected pollination, assimilate accumulation, and grain filling. These results emphasize the major influence of climatic conditions on sunflower productivity under drought environments. In contrast, Factor B (sunflower hybrid) and the interaction between year and sunflower hybrid ($A \times B$) did not significantly affect seed yield.

The absence of significant differences among hybrids suggests a relatively similar response of the analysed genotypes under the environmental conditions recorded during the study period. Furthermore, the non-significant $A \times B$ interaction indicates that the rank order of hybrids was broadly maintained across the two years despite the marked difference in environmental conditions. The coefficient of variation (Table 4) reflects the strong influence of environmental stress conditions and substantial variability among experimental observations during the study period.

Table 4. Analysis of variance (ANOVA) for seed yield (kg/ ha) of sunflower hybrids cultivated at the Fundulea location during 2024 and 2025

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	Signification
Factor A (year)	1	52043904	52043904	20.1610	0.0462	*
Error	2	5162838.636	2581419.318	-	-	-
Factor B (Sunflower hybrid)	10	41353007.030	4135300.703	0.8055	> 0.05	NS
A x B interaction	10	52229516	5222951.600	1.0174	0.4463	NS
Error	40	205340977.879	5133524.447	-	-	-

NS = not significant ($p > 0.05$); * $p < 0.05$. Coefficient of Variation: 124.14%

The significant effect of the experimental year highlights the major influence of climatic conditions, particularly drought and high temperatures, on sunflower productivity. Differences observed among sunflower hybrids suggests improved adaptation to drought conditions.

The graphical representation of interannual variation in seed yield among the analysed sunflower hybrids during 2024 and 2025 was generated using Microsoft Excel (Figure 4).

Although genotype effects on seed yield were not statistically significant, several hybrids maintained above average productivity in both years. This consistent performance suggests a lower sensitivity to environmental variation and may indicate more efficient maintenance of reproductive processes under drought and heat stress. Such responses are particularly relevant for breeding programs targeting yield stability under increasingly variable climatic conditions.

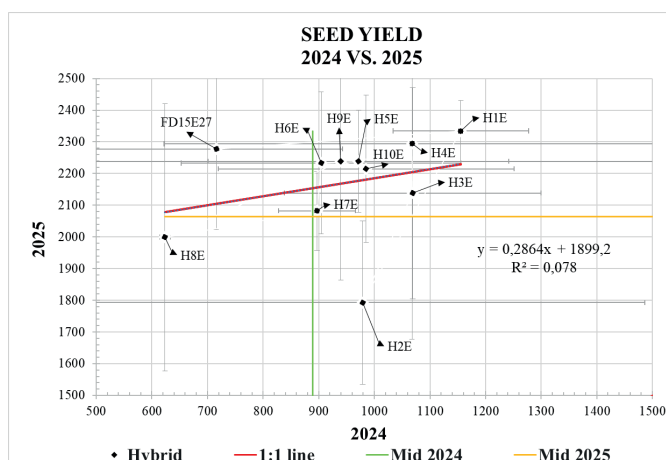


Figure 4. Interannual variation in seed yield of sunflower hybrids between 2024 and 2025

Despite the weak regression relationship between the two experimental years (Figure 4), some sunflower hybrids maintained relatively consistent productivity levels, suggesting lower sensitivity to environmental fluctuations. This observation emphasizes the importance of genotype $\times$ environment interactions in determining sunflower productivity under variable climatic conditions.

Similar reductions in sunflower seed yield under drought and heat stress conditions were reported by Duca et al. (2022), who observed significant decreases in productivity during flowering and grain filling stages. Ma'ali et al. (2024) demonstrated that water deficit negatively affects both seed yield and oil accumulation through reductions in photosynthetic activity and assimilate translocation. The accelerated flowering observed under high temperature conditions in the present study is consistent with findings reported by Domenco et al. (2023), who described shortened phenological phases under heat stress conditions.

Similar genotype $\times$ environment interactions for sunflower productivity were previously described by Syed et al. (2025), emphasizing the importance of hybrid adaptability under climatic variability. Drought stress has important effects on lipid biosynthesis and oil accumulation in sunflower seeds. Under water deficit conditions, the activity of enzymes involved in fatty acid synthesis may be reduced, while accelerated senescence and limited assimilate availability can decrease oil deposition within developing seeds. High temperatures during

grain filling may further intensify these effects by shortening the duration of seed development and reducing the period available for lipid accumulation (Table 5).

Table 5. Average seed oil content (%) of sunflower hybrids cultivated in Fundulea, in 2024 and 2025

Sunflower hybrid	Average seed oil content (%) in 2024	Average seed oil content (%) in 2025	Average by hybrid
FD15E27 check	45.8	41.71	43.75
H1E	36.20	33.68	34.94
H2E	39.95	36.32	38.13
H3E	36.33	35.69	36.01
H4E	35.49	37.47	36.48
H5E	42.49	39.25	40.87
H6E	38.25	35.13	36.69
H7E	40.91	37.61	39.26
H8E	35.20	31.58	33.39
H9E	37.28	35.04	36.16
H10E	41.18	35.80	38.49
Average by year	39.01	36.30	37.65

Analysis of variance (ANOVA) indicated that the experimental year did not significantly influence seed oil content at the 5% significance level, although a clear tendency toward significance was observed. Although the F value for Factor A (year) was relatively high, the corresponding probability value remained non-significant because the denominator error term associated with Factor A had only 2 degrees of freedom. Under these conditions, relatively high F values may still correspond to non-significant probability levels.

Since Factor A included only two levels (2024 and 2025), additional multiple-comparison procedures such as Tukey's test were not

necessary, as the ANOVA is equivalent to a pairwise comparison between years. The observed numerical reduction in seed oil content in 2025 indicates a biological tendency toward reduced oil accumulation under less favorable climatic conditions. Factor B (sunflower hybrid) had a highly significant effect on seed oil content (Table 6). Tukey HSD test (Tukey’s Honestly Significant Difference) for sunflower hybrids (Factor B) has value HSD of 3.25 at $p < 0.05$. The significant genotype effect demonstrates that oil accumulation was more strongly controlled by genetic factors than by annual climatic variation. Sunflower hybrids with consistently higher oil content across years may provide useful germplasm for breeding programs targeting oil production under water limited environments. The interaction between year and sunflower hybrid ($A \times B$) was significant at the threshold

level, suggesting that the response of sunflower hybrids regarding oil accumulation varied depending on the environmental conditions recorded during the two experimental years. The observed genotype dependent response of oil content is consistent with previous studies showing that drought and heat stress reduce lipid accumulation through limitations in carbon assimilation and fatty acid biosynthesis. Similar findings have been reported in previous studies, which demonstrated that drought stress during flowering and grain filling reduces oil accumulation through limitations in carbon assimilation and metabolic activity involved in lipid biosynthesis (Duca et al., 2022; Ma’ali et al., 2024). Other authors also reported that high temperatures during reproductive stages accelerate seed maturation and reduce the duration available for oil deposition in sunflower seeds (Momna et al., 2023).

Table 6. Analysis of variance (ANOVA) for seed oil content of sunflower hybrids in Fundulea location, in 2024 and 2025

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	Signification
Factor A (year)	1	123.875	123.875	11.7582	0.0755	NS
Error	2	21.070	10.535	-	-	-
Factor B (Sunflower hybrid)	10	497.682	49.768	17.8577	0.000	***
A x B interaction	10	57.760	5.776	2.0725	0.0505	*
Error	40	111.478	2.787	-	-	-

NS = not significant ($p > 0.05$); * $p < 0.05$; *** $p < 0.001$
Coefficient of Variation = (CV) 4.43%

The low coefficient of variation ($CV = 4.43\%$) indicates good experimental precision and relatively low residual variability within the experiment.

The graphical representation of interannual variation in seed oil content among the analysed sunflower hybrids during 2024 and 2025 was generated using Microsoft Excel (Figure 5).

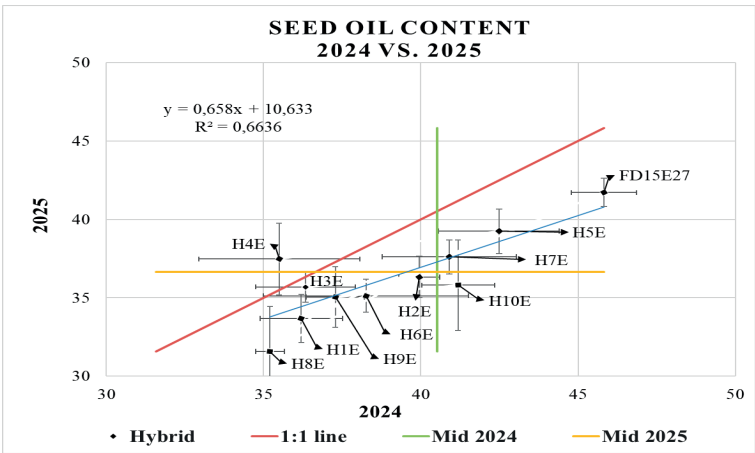


Figure 5. Interannual variation in seed oil content of sunflower hybrids between 2024 and 2025

Several hybrids maintained relatively high oil content in both years, indicating greater stability of oil accumulation under contrasting environmental conditions. This stability is of practical importance because oil yield is a primary breeding objective in sunflower. Drought and high temperature stress occurring during grain filling are known to negatively affect lipid biosynthesis by reducing photosynthetic activity, assimilate availability, and the activity of enzymes involved in fatty acid synthesis. Under severe water deficit conditions, accelerated plant senescence and shortened seed filling duration may further reduce oil accumulation in sunflower seeds. The regression relationship between years ($R^2 = 0.6636$) indicates a moderate positive correlation for seed oil content, demonstrating that hybrids with higher oil content in 2024 generally maintained relatively higher values in 2025. Total oil production per hectare was calculated using the following formula:

$$\text{Total oil} = \frac{\text{Seed yield (kg/ha)} \times \text{Seed oil content (\%)}}{100}$$

Total oil production reflected the combined effects of seed yield and oil content. Sunflower hybrids maintaining favorable values for both traits produced higher oil yields, highlighting the importance of simultaneous selection for productivity and oil accumulation (Table 7). From a breeding perspective, total oil

production may provide a more informative criterion than either trait considered separately

Table 7. Total oil production registered by sunflower hybrids in Fundulea location, in 2024 and 2025

Sunflower hybrid	Total oil (kg/ha) in 2024	Total oil (kg/ha) in 2025	Average by hybrid
FD15E27	327.47	949.73	638.60
Check			
H1E	418.11	786.09	602.10
H2E	391.11	650.85	520.98
H3E	388.36	763.05	575.71
H4E	378.67	859.56	619.12
H5E	412.57	878.41	645.49
H6E	345.78	784.45	565.11
H7E	366.96	783.04	575.00
H8E	219.29	631.28	425.29
H9E	350.05	784.195	567.12
H10E	405.62	792.61	599.11
Average by year	365.52	786.62	576.07

The relationship between productivity and oil content is strongly influenced by environmental conditions. Under severe drought stress, reductions in seed yield are frequently accompanied by lower oil accumulation due to metabolic activity during seed filling. Some sunflower hybrids may maintain relatively stable oil content despite reduced productivity, indicating better physiological adaptation and higher tolerance to abiotic stress. Hectolitre weight of the analysed sunflower hybrids differed between the two experimental years (Table 8).

Table 8. Average hectolitre weight (kg/hl) of sunflower hybrids evaluated at the Fundulea location in 2024 and 2025

Sunflower hybrid	Average hectolitre weight (kg/hl) in 2024	Average hectolitre weight (kg/hl) in 2025	Average by hybrid
FD15E27			
Check	39	37	38
H1E	36.6	33.8	35.2
H2E	38.5	33.6	36.05
H3E	34.9	35.5	35.2
H4E	34.2	32.5	33.35
H5E	36.6	34.7	35.65
H6E	35.8	34.5	35.15
H7E	35.8	33.6	34.7
H8E	36.2	35.2	35.7
H9E	34.6	34	34.3
H10E	37.3	36.3	36.8
Average by year	36.3	34.6	35.45

Analysis of variance (ANOVA) for hectolitre weight (kg/hl) of sunflower hybrids cultivated in Fundulea location during 2024 and 2025 indicated that Factor A (year) did not significantly influence hectolitre weight, although the result was close to the significance

threshold still ecologically meaningful given the drought contrast between 2024 and 2025, but no longer statistically significant at the conventional level (Table 9). Climatic conditions had a strong biological effect but the statistical evidence is marginal with only 2

error degree of freedom for Factor A. This is a power limitation of the design, not absence of an effect.

Factor B (sunflower hybrid) significantly affected hectolitre weight, indicating the existence of genetic variability among the analysed hybrids for this quality trait.

Tukey test for sunflower hybrids (Factor B) has HSD value of 3.69 at $p < 0.05$.

The significant genotype effect indicates that seed density was influenced primarily by genetic factors. Hectolitre weight is closely associated with seed filling efficiency and may therefore serve as an indicator of the ability of genotypes to maintain grain development under drought conditions.

The relatively stable hectolitre weight observed across hybrids suggests that this trait was less affected by environmental variability than seed yield, although drought and elevated temperatures likely contributed to reductions in seed filling and seed density during the experimental period.

The interaction between year and sunflower hybrid ($A \times B$) was not significant, suggesting relatively stable hybrid responses across the two experimental years.

The low coefficient of variation, indicates good experimental precision and relatively low residual variability within the experiment.

Table 9. Analysis of variance (ANOVA) for hectolitre weight (kg/hl) of sunflower hybrids in Fundulea location, in 2024 and 2025

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	Signification
Factor A (year)	1	47.702	47.702	17.8641	0.0517	NS
Error	2	5.341	2.670	-	-	-
Factor B (Sunflower hybrid)	10	91.460	9.146	2.5516	0.0174	*
A x B interaction	10	28.866	2.887	0.8053	0.81	NS
Error	40	143.375	3.584	-	-	-

NS = not significant ($p > 0.05$); * $p < 0.05$;
Coefficient of Variation (CV) = 5.34%

Interannual variation in hectolitre weight (kg/hl) of the analysed sunflower hybrids during

2024 and 2025 was graphically represented using Microsoft Excel (Figure 6).

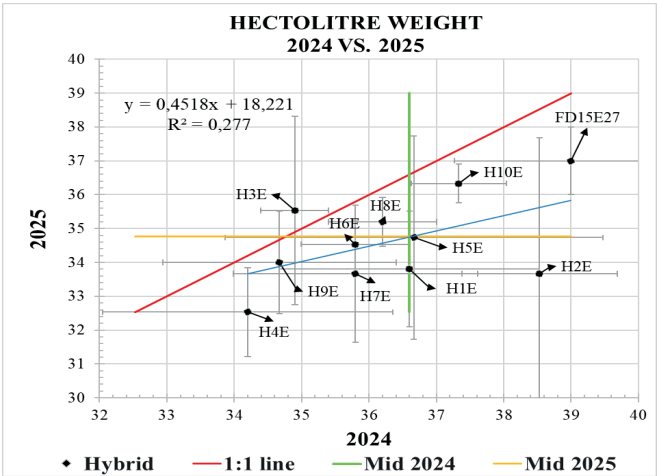


Figure 6. Interannual stability of hectolitre weight (kg/hl) in sunflower hybrids between 2024 and 2025

The regression model, indicates a moderate but relatively weak relationship between the two years.

The moderate relationship observed between years suggests that hectolitre weight was

influenced by both genetic and environmental factors. Compared with seed yield, this trait showed greater stability across years, indicating that seed physical quality was less sensitive to climatic variation than productivity. Sunflower

genotypes combining acceptable hectolitre weight with stable yield and oil content may represent useful breeding material for drought prone environments.

CONCLUSIONS

Drought and high temperatures during the flowering and seed filling periods reduced seed yield, oil content, and hectolitre weight in sunflower under the environmental conditions of Fundulea in 2024 and 2025.

Seed oil content and hectolitre weight were influenced mainly by genotype, whereas seed yield was more strongly affected by annual climatic variation, confirming the importance of genotype $\times$ environment interactions.

Experimental sunflower hybrids H1E, H4E, H5E, H6E, and H10E maintained comparatively stable yield and oil content across the two study years, indicating their potential suitability for cultivation under variable climatic conditions.

These results support the use of stability based selection criteria in sunflower breeding and cultivar evaluation programs targeting drought prone environments.

The evaluated sunflower hybrids and their parental lines represent useful genetic material for breeding programs aimed at improving adaptation to water limited conditions while maintaining acceptable productivity and oil quality.

Additional multi year and multi location studies are required to confirm the consistency of sunflower hybrid performance and their adaptation across a wider range of environments.

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