EVALUATION OF SUNFLOWER CULTIVARS TO DROUGHT STRESS IN DIFFERENT STAGES OF PHENOLOGY

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Abstract - In order to evaluate sunflower cultivars under drought stress, an experiment was conducted in 2024 on four sunflower cultivars in split plots in a randomized complete block design with 3 replications at the West Azerbaijan Research Center, Khoy. Drought stress treatment was applied at four levels in the main plots including: no water stress, stress at tillering stage, stress at flowering stage, stress at grain filling stage, and hybrids, Euroflor, Azargol and open-pollinated cultivars Master and Lakomka were considered in subplots. The results showed that the effect of main and sub-factors on agronomic traits and also The interaction effect of drought stress × cultivar on grain yield, biological yield, and harvest index was significant at the ($P \leq 0.01$), As the Azargol variety, in the presence of stress in head formation, reduces its yield by 9.68%, while the Euroflor variety shows a 18.24% decrease. Alsot the Azargol cultivar, in the presence of flowering stress, reduces its yield by 28.57%, while the Euroflor cultivar shows a reduction of 37.17%. Finally, the Azargol cultivar reduces its yield by 18.86% in the presence of grain filling stress, while the Lakumka cultivar showed a 25.64% reduction. Also, in the presence of stress, the Master cultivar showed the lowest reduction in harvest index at the stage of head formation and grain filling (7.08% and 5.25%, respectively) compared to the Euroflor cultivar (10.94%) and (8.31%), and the Lakomka cultivar showed the lowest reduction of 5.18% at the flowering stage under stress conditions compared to the Master (8.45%), Azargol (7.33%), and Euroflor (9.8%). In the results obtained from biological performance, the Azargol cultivar showed the lowest reduction in all three stages of head formation, flowering, and grain filling, respectively, by 3.05%, 18.19%, and 4.07%, compared to the Master cultivar (22.84%), (26.95%), and (20.16%).

Keywords: sunflower, stress, yield, azargol

Introduction

Environmental stresses are considered one of the most important factors reducing the yield and production of crops, and combating or reducing the effects of stresses has been considered as a useful strategy to increase the yield of these crops. Drought stress is one of the major challenges for the successful production of crops, and in this regard, breeding advanced and tolerant varieties for arid and semi-arid regions seems essential. Sunflower is one of the main sources of vegetable oil in the world and Iran. Water deficit during the growing season of sunflower can reduce net photosynthesis by reducing leaf area, closing stomata, and reducing the efficiency of carbon dioxide absorption. Water deficit stress during the growing season reduces the dry weight of leaves, stems, and roots, and also increases the root to aerial ratio due to deeper roots. Despite relative drought tolerance, water shortage is one of the most important factors limiting sunflower cultivation in Iran and the world. expanding the area under cultivation and increasing the production of sunflowers requires the introduction of cultivars adapted to dry and semi-arid conditions (Zareei Siahbidi et al, 2020). Sunflower hybrid varieties have very desirable characteristics in terms of uniformity, disease resistance, and yield. to their genetic homogeneity, they are very sensitive to changes in the growing environment. In contrast, open-pollinated varieties are less sensitive to changes in environmental conditions due to their heterogeneous genetic makeup and show good adaptability in different conditions. In addition, open-pollinated varieties are a very suitable option for cultivation

in dryland areas and areas with agricultural restrictions. In all cross-pollinated plants, hybrid varieties have high yields due to the heterosis phenomenon, and single-cross hybrids are more performance compared to other types of hybrids. Commercial varieties are low yielding and uneven, such as Record, Armavirskiy and Chernyanka. Hybrid varieties such as Azargol, Eurflor, lakomka and Master are high yielding and more uniform (Ghaffari et al., 2021). In this research, Euroflor and Azargol cultivars were considered as single-cross hybrids, and Lakomka and Master cultivars were considered as open-pollinated cultivars. The Azargol hybrid was of Iranian origin and the rest were Iranian-Russian. All four cultivars had a growth period of 110 to 120 days and were resistant to plasmospora disease. This plant has received increasing attention over the past few decades due to its beneficial fatty acids. Evaluation of various characteristics, especially the performance of genotypes under normal and moisture stress conditions, allows the identification of tolerant genotypes (Tarig et al., 2021). introducing tolerant genotypes into breeding programs, an effective step can be taken to reduce the adverse effects of drought stress and human food security (Gholamhoseini et al., 2013). In order to evaluate and identify tolerant and sensitive genotypes, several methods have been proposed by researchers in this field, one of which is the use of stress tolerance and sensitivity indices (Nawar et al, 2020; Darbani et al, 2020). In this Research, given that the cultivars considered for cultivation had acceptable yields, it was decided to examine these cultivars under stress conditions and at different phenological stages to see which cultivars gave acceptable yields at different times of stress.

Materials and methods

In order to evaluate sunflower cultivars under the influence of water shortage stress, an experiment was conducted on four sunflower cultivars in the form of a split plot in the form of a basic randomized complete block design in 3 replications at the research farm of Khoy Agricultural Research Station in 2024. Stress treatment was carried out at four levels including: no water stress, stress during tillering, stress at the flowering stage, stress at the seed filling stage in the main plots and cultivars at four levels including Master, Lakomka and Euroflor

and Azargol hybrids in the secondary plots. The seeds were obtained from the Karaj Seedling and Seed Institute, and the goal was to breed these varieties under stress conditions and adapt to the Azerbaijani climate. The project implementation site has a semi-arid climate and is located at 58°44′ north latitude and 33°48′ east latitude, and its altitude is 1142m above sea level. Planting was done on land that had been fallow the previous year. Bed preparation operations included plowing, spring discing, and leveling. A period of 120 days passed from planting to harvest. In order to determine some physical and chemical characteristics related to the soil of the test site before implementing the project, a sample of the soil composite was prepared from an average depth of 30 cm and sent to the soil science laboratory of the Soil and Water Research Department of the Agriculture and Natural Resources Research Center of West Azerbaijan (Table 1).

Simultaneously with the land preparation operation, 150 kg.ha⁻¹ of diammonium phosphate fertilizer and 100 kg of potassium sulfate were applied to the land. Also, 100 kg.ha⁻¹ of urea fertilizer was evenly distributed in three stages: at planting, at the 5-leaf stage, and at the beginning of flowering in the experimental units. In this experiment, each sub-plot had 4 planting lines at 60 cm intervals, 5 m long, and an area of 12 m². After planting, initial irrigation was performed every 5 days until the plants were established and then until the end of the season based on 80 mm of evaporation from the class A evaporation pan. In stress treatments, depending on the stress stage, irrigation was performed when the evaporation rate from the class A evaporation pan reached 110 mm, and subsequent irrigations were performed according to normal conditions (irrigation after 80 mm from the class A evaporation pan). Stress treatments were applied at four levels including: no water stress, stress at pod formation, stress at flowering stage, stress at seed filling stage and irrigation time including irrigation at 80 (control), 100, 110 and 120 mm evaporation from class A pan as main factors. Also, Master, Lakomka and Euroflor and Azergol hybrids were placed in subplots. At harvest time, traits such as number of grain per head, head diameter, 1000 grain weight, biological yield, harvest index, and sunflower seed yield were measured as follows. For thousand seed weight measurement, three 100-seed samples from each plot were counted and weighed after drying in an oven. Finally, the average weight obtained was multiplied by 10 and recorded as thousand seed weight. For biological yield, the whole plant was placed in an oven at

Table 1. Physico-chemical properties of soil experimental location

sand	Silt	Clay	pH	Soil saturation	P available (ppm)	K available (ppm)	Fe avalable (ppm)	Total N	OC
18	36	46	7.8	46	9.4	361	4.9	0.08	0.87

75°C for 48 hours and weighed. Then, by taking a sample of the obtained seeds, one thousand seeds were counted and then the weight of 1000 grain weight was measured using a precision balance (accuracy 0.01 g). To calculate the harvest index, the number of seven harvested samples after separating the seeds from the pod and drying in an oven (48 hours at 72°C) was weighed and the following formula was used: Harvest index = yield / (biological yield) × 100

STATISTICAL ANALYSIS

The resulting data were statistically analyzed with Minitab 14 software and the averages of main and interaction effects were compared with the LSD test at the five percent probability level.

RESULTS AND DISCUSSION

Grain yield

The results of the analysis of variance of the data showed that there was a significant difference in grain yield at the level ($P \leq 0.01$) between different levels of stress as the main plot, cultivars in the subplot and their interaction effects (Table 2). Azargol variety, in the presence of stress in head formation, reduces its yield by 9.68%, while the Euroflor variety shows a 18.24% decrease. Alsot the Azargol cultivar, in the presence of flowering stress, reduces its yield by 28.57%, while the Euroflor cultivar shows a reduction of 37.17%. Finally, the Azargol cultivar reduces its yield by 18.86% in the presence of grain filling stress, while the Lakumka cultivar showed a 25.64% reduction. Also, the results of the interaction effects showed that the Azargol cultivar had the highest yield in non-stressed conditions with 3084 kg, and the Master cultivar had the lowest grain yield in the grain formation stage with 2654 kg (Table 4). Azargol cultivar has better yield than other cultivars under stress and non-stress conditions, and also stress at the grain formation stage until the end of the growth period, considering that the plant is exposed to drought stress for a longer period, has the greatest effect on yield components. Duca & Domenco (2022) also reported that the occurrence of severe water deficit stress during flowering, pollination, and grain setting stages causes a severe reduction in sunflower seed yield. Jocković et al. (2024) stated that an unfavorable irrigation regime, while reducing the surface area of leaves and their premature aging, causes a decrease in seed yield.

Harvest index

The results showed that the harvest index was also affected by stress × cultivar. (Table 2), in the presence of stress, the Master cultivar showed the lowest reduction in harvest index at the stage of head formation and grain filling (7.08% and 5.25%, respectively) compared to the Euroflor cultivar (10.94%) and (8.31%), and the Lakomka cultivar showed the lowest reduction of 5.18% at the flowering stage under stress conditions compared to the Master (8.45%), Azargol (7.33%), and Euroflor (9.8%). The highest harvest index in non-stress conditions was for the Euroflor variety with 25.27% at the grain filling stage and the lowest was for the Lakumka variety with 23.16% at the grain filling stage (Table 4). Ali et al. (2024) reported that due to the decrease in grain yield and biological yield due to low irrigation, the yield index of hybrids increased, so that under mild stress conditions, the yield index of the Farrokh, Shams, Ghasem and Barzegar hybrids increased by 18, 4, 15 and 3 %, respectively, and this increase under severe stress conditions was equal to 5, 21, 5 and 7 %, respectively. Increasing harvest index in the studied hybrids under both limited irrigation conditions resulted in a more severe decrease in biological yield compared to grain yield. The results of Sandoval et al., (2024) also showed that mild drought stress increases the harvest index. In the study of Saylak et al. (2024), no significant changes in the harvest index of the studied genotypes were observed due to drought stress. Giannini et al. (2024) reported that the reduction in harvest index was not large compared to the reduction in grain yield, indicating that the rate of grain yield reduction was only slightly higher than the rate of plant dry matter reduction. However, in several other studies, drought stress caused a significant reduction in harvest index (Masumi et al., 2021; Umar & Siddiqui., 2020). The reduction in harvest index resulted in a decrease in the number of grains per head, a decrease in head diameter, and an increase in grain porosity (Hussein et al., 2018). This indicates that drought stress leads to a decrease in the biological yield of plants and an increase in the harvest index of the treatments, which is consistent with the results of this study.

Biological yield

Biological yield showed significant differences between different levels of stress, cultivar and their interactions at the ($P \leq 0.01$) (Table 1). In the results obtained from biological performance, the Azargol cultivar showed the lowest reduction in all three stages of head formation, flowering, and grain filling, respectively, by 3.05%, 18.19%, and 4.07%, compared to the Master cultivar (22.84%), (26.95%), and (20.16%), Also, the Azargol cultivar had the highest biological yield in non-stressed conditions with 15,500 kg, and the Master

cultivar had the lowest biological yield in the seed formation stage with 12,350 kg (Tables 2 and 4). In the experiment (Joseph et al, 2025), it was found that mild and severe drought stress reduced the biological yield of sunflower by 43 and 69%, respectively. The reduction in biological yield due to drought stress can be due to the reduction in leaf area and the reduction in plant growth rate (Mendes et al., 2025; Avetisyan & Cvetanova (2022). In the study of Önemli et al. (2023), biological yield also decreased under stress conditions at the flowering stage, and this decrease caused a decrease in leaf area index and crop growth rate. They also reported that the rate of decrease in dry matter in plants under drought stress was greater than the rate of decrease in grain yield.

1000 grain weight

The 1000 grain weight for different stress levels and cultivars was significant at the ($P \leq 0.01$) (Table 2) Azargol variety, in the presence of stress in head formation, reduces its weight 1000 grain by 10.14%, while the Euroflor variety shows a 17.03% decrease. Alsot the Master cultivar, in the presence of flowering stress, reduces its yield by 9.18%, while the lakomka cultivar shows a reduction of 21.02%. Finally, the Azargol cultivar reduces its weight 1000 grain by 5.7% in the presence of grain filling stress, while the master cultivar showed 9.28% reduction., Also, the Azargol cultivar had the highest 1000 grain weight in non-stressed conditions with 78.65gr, and the Master cultivar had the lowest 1000 grain weight in the filling formation stage with 76.73 gr (Table 3). Centorame et al., (2024) showed that the effect of drought stress on the physical characteristics of sunflower seeds, including length, width, and diameter, was negative, and the reason for this was due to the reduction in the production of photosynthetic materials required for seed filling, which ultimately caused the seeds to shrink and reduce the 1000 grain weight. In the experiment (Smaeili et al., 2022; Tariq et al., 2021), it was reported that by stopping irrigation from the flowering stage in sunflower, the number of seeds per plant decreased and the competition for photosynthetic materials decreased, and the weight of seeds increased. It seems that moisture stress, through a decrease in leaf area, caused a decrease in seed weight and the number of seeds per plant. The competition between fertile florets and seeds on the surface for the absorption of photosynthetic materials was not intense in the Lakomka cultivar, which ultimately led to an increase in the seed weight of this cultivar.

The number of grain in head

Given that there was no significant difference in the number of grains between different stress levels, it seems that the 1000 grain weight is the most effective factor in the difference in performance at different stress levels. For the number of grains per head, there was no significant difference between different levels of moisture stress and the interaction effects of stress × cultivar However, cultivars had a significant effect on this trait at the ($P \leq 0.01$) .(Table 2), Euroflor variety, in the presence of stress in head formation, reduces its The number of grain in head by 5.16%, while the Lakomka variety shows a 18.45% decrease. Also the Azargol cultivar, in the presence of flowering stress, reduces its The number of grain in head by 7.46%, while the lakomka cultivar shows a reduction of 21.59%. Finally, the Azargol cultivar reduces its The number of grain in head by 9.4% in the presence of grain filling stress, while the master cultivar showed 24.68% reduction, Also, the Euroflor cultivar had the highest The number of grain in head in non-stressed conditions with 794, and the Lakomka cultivar had the lowest The number of grain in head in the filling formation stage with 620.

Head diameter

There was a highly significant difference between different levels of stress and cultivars in terms of head diameter (P ≤ 0.01). Azargol variety, in the presence of stress in head formation, reduces its head diameter by 19.95%, while the Master variety shows a 29.55% decrease. Also the Azargol cultivar, in the presence of flowering stress, reduces its head diameter by 11.26%, while the lakomka cultivar shows a reduction of 25.10%. Finally, the Azargol cultivar reduces its head diameter by 17.19% in the presence of grain filling stress, while the Master cultivar showed 24.27% reduction, but their intersept effects did not show a significant difference (Table 2). Also, the Lakomka cultivar had the highest head diameter in non-stressed conditions with 22.8cm, and the Euroflor cultivar had the lowest head diameter in the filling formation stage with 20.2cm. (Table 2).(Akhtar et al., 2024; Sah et al., 2020) showed that the maximum stem diameter of 17.2 cm and the maximum yield of 5124 kg.ha^{-1} belonged to the treatment of 70-70-70 mm evaporation from the surface of the pan, class A evaporation, respectively, from the stage of plant establishment to the appearance of the head, to physiological maturity., and the two cultivars of Record and High Sun 33 showed better grain yield. The occurrence of drought stress during the vegetative period causes a decrease in the number of leaves and finally the leaf surface, and as a result, the total photosynthetic materials produced for proper growth and high yield are reduced. The continuation of the low water stress process in the stage of emergence until pollination causes a decrease in the diameter of the stalk due to the decrease in the transfer of photosynthetic materials, and finally, the occurrence of drought stress in the reproductive stage can have a significant effect on the head diameter. Other tests have also been reported by (Tariq et

Table 2. Results of analysis of variance of some traits affected by drought stress in different sunflower cultivars

s.o.v	df	Grain yield	biological yield	harvest index	1000 grain weight	Head diameter	No. of grain in head
Replication	2	0.421^{ns}	60.80	43.813	1.071	0.813	9162.25
Stress levels A	3	13.461^{**}	323.624^{**}	30.996^{*}	317.17^{**}	156.08^{**}	122592.7^{ns}
Error A	6	1.346	28.073	7.085	3.217	11.951	112602.9
Cultivars	3	1.334^{**}	52.224^{**}	29.897^{**}	418.565^{**}	4.46^{*}	76399.2^{**}
Culti-vars*stress	9	0.646^{**}	4.673^{**}	12.803^{**}	6.202^{ns}	2.65^{ns}	10648.2^{ns}
Error B	24	0.206	1.384	4.425	2.745	1.167	4791.93
CV %		14.97	9.22	10.28	2.79	5.98	9.72

*and** are significant at the five and one percent probability levels, respectively

Table 3. Comparison of the mean of some traits affected by drought stress (main plot) in different cultivars (subplot)

Experimental factors	Head diameter	1000grain weight	harvest index	biological yield	Grain yield	No.of grain in head
Non stress	23a	78.85a	15.46b	19946 a	3084 a	814a
Stress stage formation head	14.3c	64.03d	17.09ab	7106 c	1215 c	586.7a
Stress in the flowering stage	17.5b	69.25c	17.33a	12222 b	2119 b	769a
Grain filling stage stress	17.4b	71.35b	18.22a	12696b	2314b	677.6a
master	17.7 a	66.7c	17.72ab	10536b	1867b	671.9b
Lakomka	17.6 a	80.24a	17.47a	12523ab	2189a	620.7b
Azargol	18.9a	72.20b	13.15c	15667a	2061a	760.6a
Euroflor	18.1 a	64.4d	14.27bc	13243ab	1891a	794.5a

al, 2018). Head diameter is one of the most basic traits that decreases under the influence of moisture stress and has a negative effect on yield components such as the number of seeds per head (Khoufi et al, 2013) observed that drought stress always has a negative effect on head diameter and one of the goals Sunflower breeding is the selection of genotypes with a larger diameter. The results (Janzen et al., 2023)

showed that the rate of decrease of dry matter in the plant due to drought stress was higher than the rate of decrease of grain yield. In the study of Abassi et al. (2021) it has also been pointed out that the weight of aerial organs is severely reduced due to stress. Kaya et al.(2016) reported a 22-50% reduction in the weight of aerial organs due to drought stress. Sometimes the results presented in this regard are different,

Table 4. Comparison of the average interaction effects of some traits affected by drought stress in different cultivars

Experimental factors	biological yield	Grain yield	harvest index
non Stress			
Master	16651c	2688bc	def 16.14
Lakomka	19354b	3096 b	def 15.99
Azargol	24624a	3732 a	ef 15.15
Euroflor	19150b	2736 bc	f 14.28
Stress stage formation head			
Master	6154i	1032h	16.76cdef
Lakomka	7199ih	1500gh	a 20.83
Azargol	8372ch	1308gh	ef 15.62
Euroflor	6698hi	1014h	ef 15.13
Stress in the flowering stage			
Master	9860fg	1872ef	18.98abc
Lakomka	10769f	1740 efg	16.15cdef
Azargol	14926c	2580 bcd	17.28 bcde
Euroflor	13336de	2262 cde	16.96 bcde
Grain filling stage stress			
Master	9477fg	1878ef	19.81ab
Lakomka	12733e	2040 bcd	16.02a
Azargol	14747d	2142 de	14.52ef
Euroflor	13787de	2580 bcd	18.71 abcd

so that in the study of Mohammadi Alagoz et al., (2023), the decrease in grain yield was greater than the decrease in biological yield (Ahmed et al., 2024).

Averages with common letters in each column have no significant difference at the five percent probability level with Duncan's test

and open-pollinated sunflower cultivars were evaluated under drought stress conditions and at different phenological stages, and among them, the Azargol cultivar is introduced as the superior cultivar due to the least reduction in grain yield under water deficit conditions, which is probably due to the less reduction in photosynthesis, enzymatic activity, and re-transfer of storage materials from other organs to seeds, and as a result, less reduction in the weight of filled seeds.

Conclusions

Given that most countries, including Iran, will face water crises in the future, genetic improvement and introduction of drought-resistant cultivars are essential. In this study, hybrid

Funding Declaration

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