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Effect of irrigation and foliar spraying of salicylic acid and humic acid on yield and water use efficiency of sunflower (*Helianthus annuus* L.)

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To investigate the effect of irrigation levels, humic acid, and salicylic acid on the yield and water use efficiency of sunflower, a split factorial experiment based on a randomized complete blocks design with three replications was conducted in the research farm of Islamic Azad University, Birjand branch. Treatments consisted of irrigation at two levels (120 and 240 mm of evaporation from the pan) in the main plots, humic acid at three levels (0, 20, and 40 L. ha^{-1}), and salicylic acid at two levels (0 and 0.75 mM) in a factorial combination in sub-plots. The results showed that the highest number of seeds per head (215.9 seeds), 1000 seed weight (40 g), seed yield (1126.9 kg ha^{-1}), biological yield (4320 kg ha^{-1}), harvest index (25.9%), oil percentage (38.7%), oil yield (440 kg ha^{-1}), protein yield (208.5 kg ha^{-1}), water use efficiency for protein production (18.1 kg m^{-3}) and water use efficiency for oil production (38.2 kg m^{-3}) were related to treatment irrigation level of 120 mm evaporation from the pan and the highest percentage of protein (22.8%) was obtained from the irrigation level of 240 mm evaporation from the pan. Applying 20 liters per hectare of humic acid in the irrigation cycle of 120 mm evaporation from the pan increased the number of seeds in the head. In contrast, the application of humic acid decreased this trait. Applying salicylic acid increased the number of seeds per head, water use efficiency for oil production, while the oil yield decreased. Also, salicylic acid under water stress improved protein percentage and oil yield. Based on the results of this research, to achieve the maximum grain yield, protein yield, and sunflower oil yield in the Birjand region, irrigation treatment can be used after 120 mm of cumulative evaporation from the evaporation pan and consumption of 0.75 mM salicylic acid.

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Introduction

Sunflower (*Helianthus annuus* L.) is an annual and variable plant that is the fifth most important crop in the world after soybean, rapeseed, cotton, and peanut, which is cultivated for its edible oil and nut consumption (Babec et al., 2020). Sunflower is one of the most important oilseed plants in the world, and its oil is of high quality due to its abundant unsaturated fatty acids and lack of cholesterol (Ghendov-Mosanu et al., 2023). This plant is a drought-tolerant crop with a deep root system, and its cultivation has been developed in arid and semi-arid lands. Due to its high adaptability to different conditions, high yield of oil, high nutritional value, and lack of anti-nutritional factors, its cultivated area has increased (Smaeili et al., 2022). Seed oil content is considered an index of sunflower breeding and an important component in oil yield. This complex trait is determined by environmental and genetic factors, which themselves depend on seed yield and related traits (Ebrahimian et al., 2019).

One of the most important factors limiting the growth of agricultural plants is the lack of water (Javadi et al., 2022). Dehydration stress is one of the most effective growth-limiting factors in Sunflower (Khalilvand Behrouzyar and Yarnia, 2014). The results of several studies showed that the yield and yield components of sunflower decreased with increasing water deficit (Seyed Sharife and Seyed Sharife, 2019; Moradi Ghahderijani et al., 2015; Gholinezhad and Darvishzadeh, 2018). In a research, the highest seed yield and oil percentage of sunflower seeds were obtained from the discharge of 40% of usable soil moisture (Jami et al., 2018). In a research that was conducted to investigate four irrigation levels of 40, 60, 80 and 100% of potential evaporation and transpiration during the growing season of sunflower in the calcareous soil of East Azarbaijan, the lack of water caused a decrease in seed yield through a decrease in seed weight and number of seeds per plant. (Ebrahimian et al., 2019).

One of the appropriate solutions to reduce the effects of drought is the use of substances such as humic acid and salicylic acid, which, with their stress-modulating properties, can partially compensate for the decrease in yield caused by drought (Movahhedi-Dehnavi et al., 2019). Humic acid increases the population of soil organisms, improves the physical condition of the soil, adjusts pH, and has enzymatic and hormonal effects on plant growth. Also, humic acid's benefits are increasing plant resistance to drought and salinity stress, increasing nutrient absorption, increasing germination and root growth, and improving quantitative and qualitative yield (Rehman et al., 2023). Among the organic compounds, humic acid can act as one of the important and alternative compounds in meeting the nutritional needs of plants due to its chelating property of various mineral elements such as potassium, magnesium, zinc, calcium, iron, copper, and other food elements (Wyszkowski et al., 2023). Humic acid has a quasi-hormonal effect and causes an increase in root volume, and as a result, absorbs more nutrients (Hemati et al., 2022). Also, due to its high cation exchange capacity, humic acid provides useful elements and removes toxic elements and heavy metals in the roots of plants (Zhanga et al., 2023). In a research that was conducted to investigate the effect of three levels of humic acid on the growth characteristics and yield of sunflower, the greatest increase in the amount of oil percentage, thousand seed weight, seed weight, seed yield, seed diameter, stem diameter and number of leaves from the treatment of 3 liters of humic acid in In sufficient nitrogen conditions, the greatest increase in plant height and plant weight was obtained from the treatment of 6 liters of humic acid on sufficient nitrogen conditions, and highest percentage of protein was obtained from the treatment of 1 liter of humic acid per hectare in sufficient soil nitrogen conditions (Tadayon et al., 2021).

Salicylic acid is an important phenolic compound that functions as a plant growth regulator, playing a key role in regulating plant growth and development (Pál et al., 2020). Studies have shown that salicylic acid changes the response of plants to cold, high temperature, salinity stress, osmotic stress, and herbicides and improves plant growth under these conditions (Chen et al., 2023). Various physiological and biochemical effects of salicylic acid have been seen on plant growth and development, which include ion absorption, membrane permeability, mitochondrial respiration, stomatal closure, material transport, growth rate, and photosynthesis (Khalvandi et al., 2021). In a research, increasing the amount of salicylic acid up to 200 ppm increased the number of seeds per plant, seed yield, and sunflower oil yield (Davodi et al., 2020). In a study, foliar spraying of salicylic acid increased drought tolerance and increased seed and oil yield in sunflower (Hossini et al., 2024). Studies investigating the combined effects of humic acid and salicylic acid could be useful because both act as potential drought ameliorators. Humic acid helps root growth and proliferation to penetrate deeper into the soil, while salicylic acid enhances plant immunity to combat ROS under water-deficit conditions (Altaf et al., 2023).

Considering the importance of oil production in Iran and water shortage in the South Khorasan region, it is necessary to find a solution to reduce and moderate the effect of water shortage stress on this product. Therefore, the present study was conducted to investigate the use of humic acid and salicylic acid on the yield and water use efficiency of sunflower at different levels of irrigation in the Birjand region.

Materials and methods

Climatic conditions and soil of the test site

This experiment was carried out in the research farm of Islamic Azad University, Birjand Branch, located at 5 kilometers of the Birjand-Zahedan Road, 59′ 13° eastern longitudes and 32′ 53° northern latitudes and an altitude of 1491 m above sea level. The test site is located in a dry climatic region according to the Amberger classification system. This is characterized by a 15-year average rainfall of 156 mm and a temperature range from -17°C to 39.1°C, with a mean daily temperature of 12°C. Soil analysis results for the area are provided in Table 1.

Table 1. The results of soil analysis of the test site at a depth of 0 to 30 cm

Soil texture	Electrical conductivity ($\mu s.cm^{-1}$)	pH	Organic matter (%)	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)
Clay loam	2.23	8.47	0.12	0.011	4.09	231.5

Research method

This experiment was conducted using a split-factorial design arranged in randomized complete blocks with three replications. The main plots were assigned to two irrigation levels (120 and 240 mm of evaporation from a class A pan). The sub-plots received a factorial combination of three levels of humic acid (0, 20, and 40 L ha^{-1}) and two levels of salicylic acid (0 and 0.75 mM). Each sub-plot consisted of four 7-meter-long rows spaced 0.6 m apart, with plants thinned to a final intra-row spacing of 20 cm, resulting in a planting density of 83,333 plants per hectare.

Based on the results of the soil test, an amount of 250 kg ha^{-1} of urea was used (one third before planting, one third at the 6-8 leaf stage, and one third at the flower bud emergence stage) (Jami et al., 2018). An amount of 120 kg ha^{-1} of triple superphosphate was spread on the ground and mixed with the soil before planting. Sunflower planting was done on June 1st. The first irrigation was completed immediately after planting. After the complete establishment of the plant, to apply the irrigation treatments, the evaporation rate data was obtained from the Class A pan from the Birjand Meteorological Department, and based on that, the irrigation treatments were calculated for each plot and applied with the help of the pressure system and by the hose and meter. Foliar spraying of humic acid was done in three stages, including four leaves, emergence, and filling of seeds. The spraying of salicylic acid was implemented in two stages, immediately after complete irrigation and humic acid application on August 11 and August 25. In each foliar spraying, the control was also sprayed with normal water. Spraying was carried out in the cool hours of the afternoon (16:00 to 20:00) and on the aforementioned designated days by a back-mounted motorized sprayer with a volume of about 12 liters. Weed control was completed by hand in three rounds. During the growing season, no specific pest or disease was observed.

Study traits

To determine the yield components, four plants were randomly selected by observing specific marginal effects and yield components, as well as biological yield traits and harvest index. To determine the grain yield, the layers of the two middle rows were harvested at the time of physiological ripening (browning of the layers) after removing 0.5 m from the beginning and end of the plot. After beating, it was placed in an oven at a temperature of 70 degrees Celsius for 48 hours. Then the seed yield was determined based on 12% moisture.

To determine the percentage of oil and seed protein, the samples obtained from the treated seeds of each plot were determined in the laboratory by the Soxhlet and Kjeldahl method (Asghari and Gharibi Asl, 2016; Naseri et al., 2012). The yield of oil and protein per unit area was also obtained from the product of seed yield in oil percentage and seed protein percentage.

The following relationships were used to calculate the efficiency of seed water, oil, and protein consumption (Mousavi et al., 2010):

$$WUE = \frac{\mathrm{GY}}{\mathrm{Vw}} \quad (1)$$

$$WUE = \frac{\mathrm{OY}}{\mathrm{Vw}} \quad (2)$$

$$WUE = \frac{\mathrm{PY}}{\mathrm{Vw}} \quad (3)$$

In the above relationships, WUE is the water use efficiency (kg m^{-3}), GY, OY, and PY are respectively grain yield, oil yield, and protein yield (kg), and Vw is the total volume of irrigation water (m^{-3}).

Data analysis method

After data collection, statistical analysis was implemented using MSTATC software. To compare the means, Duncan's multiple range test was used at the 5% probability level.

Results

Yield and yield components

The analysis of variance indicated that both irrigation and salicylic acid significantly affected the number of seeds per head at the 1% probability level. Furthermore, the two-way interactions of irrigation × humic acid and irrigation × salicylic acid were significant at the 5% probability level (Table 2).

Table 2. Analysis of variance (mean square) for yield and components of grain yield of sunflower under the influence of humic acid, salicylic acid, and irrigation levels

Sources of variation	df	Number of seeds in the head	1000 seed weight	Seed yield	Biological yield	Harvest index
Replication	2	4974.0 ^{ns}	46.0 ^{ns}	256113.8 ^{ns}	4.5 ^{ns}	3733236.1 ^{ns}
Irrigation (I)	1	59108.1**	480.7**	2725525.8*	582.7**	10947275.1**
Humic acid (H)	2	809.1 ^{ns}	0.39 ^{ns}	28352.6 ^{ns}	7.2 ^{ns}	76700 ^{ns}
I × H	2	3211.2*	2.1 ^{ns}	81564.2 ^{ns}	5.0 ^{ns}	761000 ^{ns}
Error a	10	736.8	2.6	27845.5	5.2	267721.2
Salicylic acid (S)	1	7320.2**	11.2 ^{ns}	117935 ^{ns}	29.4 ^{ns}	238144 ^{ns}
S × I	1	4747.4*	26.0 ^{ns}	59984.1 ^{ns}	10.6 ^{ns}	274401.3 ^{ns}
S × H	2	572.4 ^{ns}	1.2 ^{ns}	8525.1 ^{ns}	15.9 ^{ns}	633317.1 ^{ns}
I × H × S	2	1720.8 ^{ns}	3.6 ^{ns}	58537.09 ^{ns}	15.6 ^{ns}	19630.8 ^{ns}
Error b	12	685.7	10.0	29129.8	5.2	406338.4
Coefficient of variation (%)		14.9	8.7	20	10.4	16.9

**,* and ns are significant at 1 and 5% probability levels and non-significant, respectively

The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the number of seeds in the head decreased by 37.5% (Table 3).

Table 3. Comparison of the average effect of irrigation levels on yield and grain yield components in sunflower

Irrigation levels (mm evaporation from pan)	Number of seeds in the head	1000 seed weight (g)	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
120	215.9 a	40.0 a	1126.9 a	4320.0 a	25.9 a
240	134.8 b	32.6 b	576.6 b	3217.1 b	17.9 b

Means with the same letter in each column are not significantly different based on the Duncan test ($p \leq 0.05$).

In the treatment of 120 mm of cumulative evaporation, the highest number of seeds per head belonged to 20 L ha^{-1} of humic acid (243.1), but the use of humic acid in the treatment of 240 mm of evaporation decreased the number of seeds in the head (Figure 1).

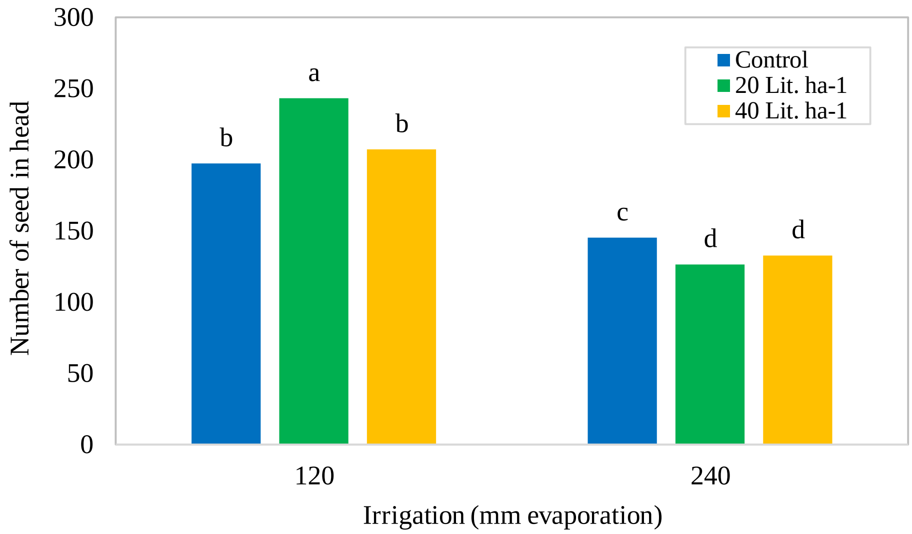

Figure 1. Comparison of the average effect of irrigation and humic acid on the number of seeds in the head of sunflower

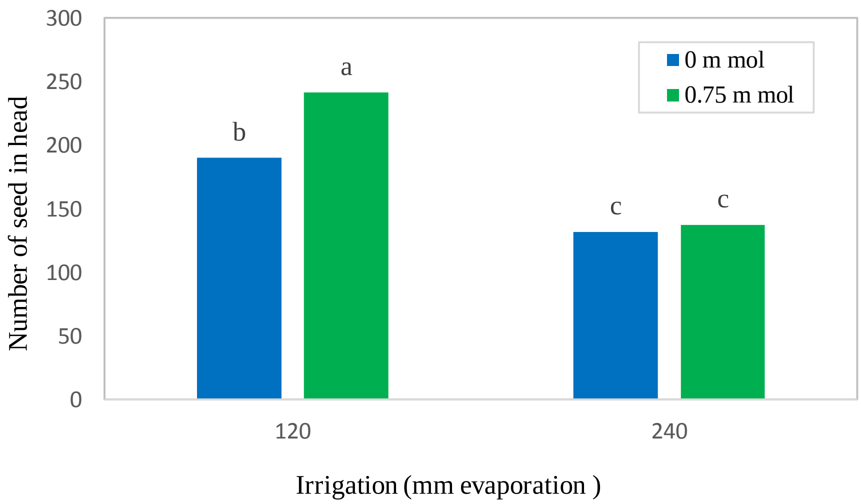

Figure 2. Comparison of the average effect of irrigation and salicylic acid on the number of seeds in the head of sunflower

The use of 0.75 mM salicylic acid increased the number of seeds in the head by 15% compared to the control (Table 4). The results of the average comparison indicated that in the treatment of 120 mm of cumulative evaporation, the use of 0.75 mM salicylic acid increased the number of seeds in the head by 27%; while the use of salicylic acid in the treatment of 240 mm cumulative evaporation did not have a significant effect on this trait (Figure 2). The results of the analysis of variance showed that the effect of irrigation cycle on the weight of 1000 seeds was significant at the 1% probability level (Table 2). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the weight of 1000 seeds decreased by 18.5% (Table 3).

The results of the analysis of variance of indicateed that the effect of irrigation period on seed yield was significant at the 5% probability level (Table 2). The comparison of the averages showed that the highest seed yield with an average of 1126.9 kg ha^{-1} was obtained from the irrigation treatment after 120 mm of cumulative evaporation from the evaporation pan, and by increasing the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the seed yield decreased by 48.8% (Table 3).

Table 4. Comparison of the average effect of salicylic acid on the number of seeds per head and the efficiency of oil water use efficiency in sunflower

Salicylic acid levels (mM)	Number of seeds in the head	Oil yield (kg ha^{-1})	Oil water use efficiency (kg m^{-3})
0	161.1 b	342.3 a	31.1 b
0.75	189.6 a	283.1 b	37.0 a

Means with the same letter in each column are not significantly different based on the Duncan test ($p \leq 0.05$).

Biological yield

The results of the variance analysis showed that the effect of irrigation cycle on biological yield was significant at the 1% probability level (Table 2). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the biological yield decreased by 25.5% (Table 3).

Harvest index

The results of the analysis of variance of the harvest index showed that the effect of the irrigation cycle on the harvest index was significant at the 1% probability level (Table 2). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the harvest index decreased by 30.8% (Table 3).

Oil percentage and oil yield

The results of the analysis of variance showed that the effect of irrigation cycle on oil percentage was significant at the 5% probability level (Table 5). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the oil percentage decreased by 16.5% (Table 6).

The results of variance analysis showed that the effect of irrigation distance and the effect of salicylic acid on oil yield were significant at the 1% probability level, and the interaction effect of irrigation and salicylic acid was significant at the 5% probability level (Table 5). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the oil yield decreased by 57.8% (Table 6).

Comparison of the averages showed that the application of 0.75 mM salicylic acid decreased the oil yield by 17.2% compared to the control (Table 4). The results of the average comparison indicated that the use of 0.75 mM salicylic acid in the treatments of 120 and 240 mm of cumulative evaporation caused an increase of 25.5 and 9.5% respectively in oil yield compared to the control (Figure 3).

Table 5. Analysis of variance (mean square) for quality traits and water use efficiency of sunflower under the influence of humic acid, salicylic acid, and irrigation levels

Sources of variation	df	Oil percentage	Protein percentage	Oil yield	Protein yield	Seed water use efficiency	Oil water use efficiency	Protein water use efficiency
Replication	2	14.1 ^{ns}	0.48 ^{ns}	40867.1 ^{ns}	9419.6 ^{ns}	2774.2 ^{ns}	343.8 ^{ns}	41.4 ^{ns}
Irrigation (I)	1	374.8*	168.4**	583238.5**	53145.4**	224 ^{ns}	627.5*	2306.7**
Humic acid (H)	2	151.3 ^{ns}	2.2 ^{ns}	17480 ^{ns}	823.4 ^{ns}	140.7 ^{ns}	173.1 ^{ns}	11.6 ^{ns}
I × H	2	7.1 ^{ns}	5.6 ^{ns}	12825.5 ^{ns}	2975.3 ^{ns}	887 ^{ns}	107.8 ^{ns}	14.6 ^{ns}
Error a	10	57.5	5.1	14280.6	739.4	285	153.3	6.5
Salicylic acid (S)	1	11.7 ^{ns}	0.16 ^{ns}	31453.9**	4129.9 ^{ns}	1123.8 ^{ns}	306.0*	18.9 ^{ns}
S × I	1	9.8 ^{ns}	5.3*	14794.1*	862.7 ^{ns}	311 ^{ns}	72.3 ^{ns}	14.3 ^{ns}
S × H	2	26.7 ^{ns}	0.9 ^{ns}	849.5 ^{ns}	556.9 ^{ns}	105.5 ^{ns}	4.0 ^{ns}	7.6 ^{ns}
I × H × S	2	41.2 ^{ns}	1.8 ^{ns}	3318.9 ^{ns}	2600.3 ^{ns}	807 ^{ns}	38.6 ^{ns}	10.5 ^{ns}
Error b	12	25.4	1/0	2777.1	1333.4	429.3	42.6	6
Coefficient of variation (%)		14.2	5	16.8	21.4	21.6	19.1	24.2

**,* and ^{ns} are significant at 1 and 5% probability levels and non-significant, respectively

Table 6. Comparison of the average effect of irrigation levels on yield, grain yield components, quality traits and water use efficiency in sunflower

Irrigation levels (mm evaporation from pan)	Oil (%)	Protein (%)	Oil yield (kg ha^{-1})	Protein yield (kg ha^{-1})	Oil water use efficiency (kg m^{-3})	Protein water use efficiency (kg m^{-3})
120	38.7 a	18.5 b	440.0 a	208.5 a	38.2 a	18.1 a
240	32.3 b	22.8 a	185.4 b	131.6 b	29.9 b	12.1 b

Means with the same letter in each column are not significantly different based on the Duncan test ($p \leq 0.05$).

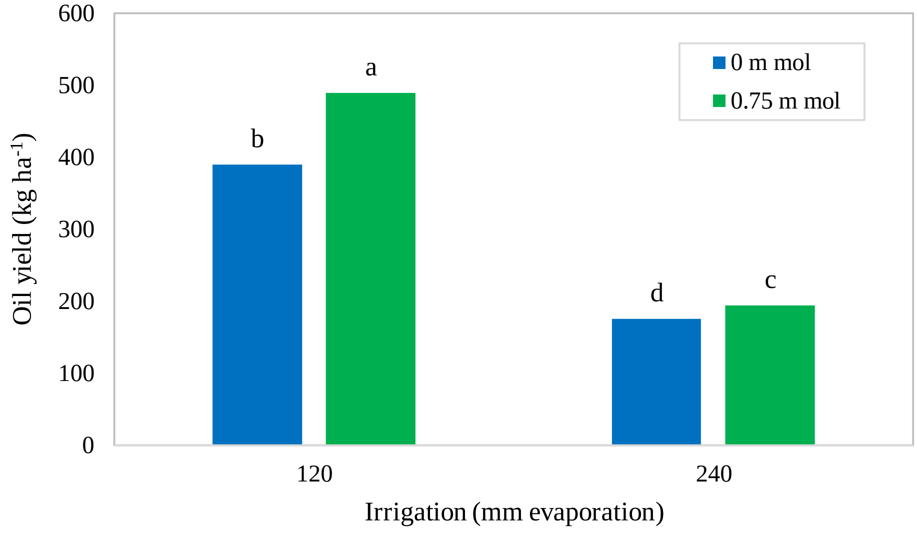

Figure 3. Comparison of the average effects of irrigation and salicylic acid on oil yield in sunflower

Protein percentage and protein yield

The results of the analysis of variance showed that the effect of irrigation cycle on protein percentage was significant at a 1% probability level, and the interaction effect of irrigation cycle and salicylic acid was significant at a 5% probability level (Table 5). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the protein percentage increased by 18.8% (Table 6). The results of the mean comparison indicated that the application of 0.75 mM salicylic acid in the treatment of 120 mm of cumulative evaporation caused a decrease of 3.1%, and 240 mm of cumulative evaporation, it caused an increase of 3.8% of seed protein compared to the control (Figure 4). The results of analysis of variance showed that the effect of irrigation period on protein yield was significant at the 1% probability level (Table 5). The comparison of the averages showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of the protein yield decreased by 36.8% (Table 6).

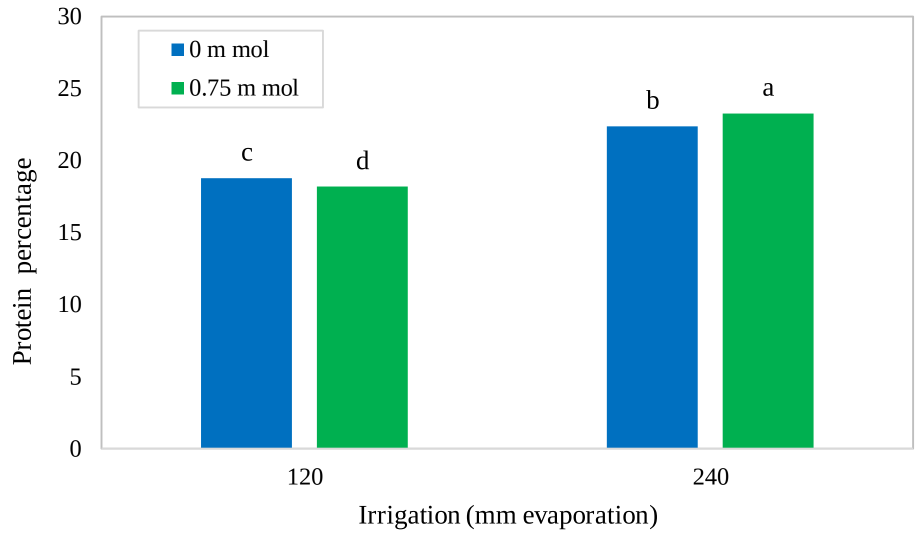

Figure 4. Comparison of the average effect of irrigation and salicylic acid on protein percentage in sunflower

Water use efficiency

The analysis of variance revealed that the effect of irrigation was significant on oil water use efficiency at the 5% level and on protein water use efficiency at the 1% level (Table 5). Also, the effect of salicylic acid on oil water use efficiency was significant at the 5% probability level (Table 5). The results of the average comparison showed that with the increase of the irrigation cycle from 120 to 240 mm, the cumulative evaporation of water, oil, and protein use efficiency decreased by 21.7 and 33.1%, respectively (Table 6). The use of 0.75 mM salicylic acid increased the efficiency of oil-water use by 15.9% compared to the control (Table 4).

Discussion

Dehydration decreased sunflower seed yield by decreasing the number of seeds per plant and the weight computed for 1000 seeds (Table 3). The results of studies by several researchers indicate a decrease in sunflower yield under water stress conditions (Seyed Sharife and Seyed Sharife, 2019; Moradi Ghahderijani et al., 2015). The occurrence of drought stress in different stages causes a decrease in the number of seeds in the field, but the percentage of this decrease is more severe in the reproductive stages. The presence of optimal environmental conditions in the flowering stage is effective in determining the number of seeds formed in the pod, and drought stress in this stage causes abortion and the production of immature seeds (Hamzei et al., 2017). Dehydration stress through the reduction of the leaf area and their fall leads to a decrease in the photosynthetic source and the activity of enzymes affecting this process, and on the other hand, it causes a decrease in the capacity of the reservoir to absorb photosynthetic materials and a decrease in the number of fertile florets on the surface of the leaf and finally the number of seeds in the leaf. (Ebrahimian et al., 2019). Drought stress due to the lack of nutrients to fill the seed caused a decrease in vegetative growth and eventually a decrease in the photosynthetic level of the plant and a decrease in the share of the seed in receiving the amount of stored carbohydrates and the weight of one thousand seeds decreased (Smaeili et al., 2022). Research results showed that sunflower seed yield decreased by about 40% in low irrigation conditions (Ghaffari et al., 2020). In this research, seed size disturbance due to increased sterility of pollen grains (Hussain et al. 2018) and photosynthetic organ damage due to premature leaf fall (Rauf and Sadaqat 2007) were the main reasons for decreased seed yield. In the present study, the reduction of yield components such as the number of seeds per plant and the weight of 1000 seeds under water stress conditions caused a decrease in seed yield.

By increasing the irrigation cycle from 120 to 240 mm, the cumulative evaporation of biological yield decreased by 25.5% (Table 3). The research results showed that the biological performance of sunflower decreased in the conditions of severe dehydration stress (150 mm evaporation from the pan) compared to no dehydration stress and mild stress (90 and 120 mm evaporation) (Esmaeili et al., 2023). Drought stress reduces the yield of three-carbon crops due to the reduction of internal carbon dioxide in the leaves and the increase of photorespiration (Amraei et al., 2017).

The harvest index is determined by the ratio of grain yield to biological yield (Esmaeili *et al*., 2023). As shown in Table 3, drought stress reduced both grain and biological yield, which consequently led to a decrease in the harvest index. This decline occurs because water scarcity impairs the plant's ability to absorb nutrients, synthesize photosynthetic products, and translocate assimilates, ultimately lowering the proportion of biomass allocated to the harvested grain (Ghasemi *et al*., 2021).

The increase in drought stress has probably reduced the percentage of oil by shortening the growth period and the duration of oil synthesis. Therefore, optimal irrigation conditions in the entire growth period have a longer period for seed filling, and the percentage of oil has also increased in this treatment. The results of a two-year research indicated that dehydration stress in sunflower caused a decrease in oil percentage (El-Bially et al., 2022).

Oil yield is a function of grain yield and oil concentration. Since dehydration stress reduced both of these components, the oil yield consequently decreased. These results align with the findings of Esmaeili et al. (2023), who reported that increased irrigation intervals (e.g., 150 mm of pan evaporation compared to 90 or 120 mm) led to a reduction in both the oil percentage and the overall oil yield of sunflower seeds. The occurrence of water stress and its increase during the growth stages of the plant limit the amount of water available to the plant and the formation of reproductive organs. As a result, the source-reservoir relationship is disrupted and ultimately leads to a decrease in grain yield. This problem will reduce the yield of oil per unit area. Also, the use of salicylic acid by creating a defense system and appropriate tolerance against unfavorable environmental conditions such as water stress in the plant, increases the yield of seeds and oil compared to the treatment of no use. The results showed that the use of salicylic acid under water stress conditions increased oil yield in sunflower (El-Bially et al., 2022; Davodi et al., 2020).

With the increase in water stress due to the decrease in the ratio of carbohydrate to protein, the percentage of grain protein increased. In a research, drought stress increased the percentage of seed protein compared to optimal irrigation conditions, they stated that the reason for this was the reduction in the transfer of photosynthetic materials, which causes a decrease in the ratio of the volume of the starchy endosperm to the total volume of the seed, and since the percentage of protein in the shell and Embryo is more starchy than endosperm, so the percentage of seed protein increases under drought stress conditions (Majdom, 2017). In another study, the reason for the increase in seed protein percentage in drought stress conditions was the increase in the intensity of respiration and the decrease in material absorption and the decrease in stored carbon hydrates (Aghjeli et al., 2018). Research results showed that irrigation until the flowering stage increased the percentage of seed protein compared to full irrigation in sunflower (Hamzei et al., 2017).

The application of salicylic acid and optimal irrigation decreased the percentage of seed protein, but with the increase of drought stress, the effect of the application of salicylic acid was favorable (Figureure 4). In a research, the lowest amount of guar seed protein was related to not using salicylic acid and optimal irrigation (6 days) (Chamani et al., 2018).

Protein yield, calculated as the product of seed yield and protein concentration, decreased significantly with increasing dehydration stress (Table 6). This decline was primarily driven by the associated reduction in grain yield (Table 3). This finding is consistent with previous research; for instance, Aghjeli *et al*. (2018) observed a decrease in mung bean protein yield under drought stress, and Barati and Ghadiri (2016) reported a 43% reduction in barley protein yield due to a severe decline in dry matter. Conversely, ensuring adequate water availability, such as irrigation during the flowering and seed-filling stages as demonstrated in safflower by Hasanvand *et al*. (2014), is critical for maintaining protein yield.

The increase in water deficit stress decreased the efficiency of water consumption in the production of sunflower seed oil and protein (Table 6). These results showed that the water stress conditions have reduced the conversion of photosynthetic materials into oil and protein. In a research conducted on different canola cultivars under drought stress and non-stress conditions, the increase in water stress caused a decrease in the efficiency of water consumption for oil production (Mousavi et al., 2010).

The use of salicylic acid increased the efficiency of water consumption in oil production (Table 4). In a research, the application of salicylic acid up to 1 mM increased the efficiency of water consumption in sunflower (El-Bially *et al.*, 2022). Water use efficiency is associated with many important physiological characteristics of plants such as stomatal conductance, photosynthesis, and osmotic regulation (Bacon, 2009). Foliar spraying of salicylic acid increased the efficiency of water consumption in oil production through the improvement of physiological processes in the plant, such as increasing the efficiency of the photosynthesis level and improving the relationship between the source and reservoir in the plant.

Conclusion

This study demonstrated that increasing the irrigation interval from 120 mm to 240 mm of cumulative evaporation reduced grain yield, protein yield, oil yield, and water use efficiency. Among the measured traits, only protein concentration increased by 18.8% under the higher irrigation interval.

The application of 0.75 mM salicylic acid enhanced water use efficiency for oil production and improved both protein concentration and oil yield under water stress conditions. Therefore, to maximize grain, protein, and oil yield in the Birjand region, an irrigation regime after 120 mm of cumulative pan evaporation combined with a 0.75 mM salicylic acid treatment is recommended. The foliar application of salicylic acid enhances drought tolerance in sunflowers, establishing it as a viable strategy for improving seed and oil yield in water-limited environments.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

Aghjeli, A., Nakhzari Moghaddam, A., Rahemi Karizaki, A., and Gholamalipour Alamdari, E. 2018. Effect of supplemental irrigation and splitting nitrogen on quantity and quality of mung bean (*Vigna radiata* L.). Environmental Stresses in Crop Sciences. 11(3), 591-602.

Altaf, A., Nawaz, F., Majeed, S., Ahsan, M., Shafique Ahmad, kh., Akhtar, G., Shehzad, M. A., Muhammad Rashad Javeed, H., and Farman, M. 2023. Foliar humic acid and salicylic acid application stimulates physiological responses and antioxidant systems to improve maize yield under water limitations. JSFA reports. 3(3): 107-145.

Amraei, B., Peknezad, F., Ebrahimi, M. A., and Subhaniyan, H. 2017. Effect of methanol foliar application and drought tension on grain yield and growth indices of soybean (*Glycine max* L.). Crop Physiology Journal. 9(34), 111-129.

Asghari, B., and Gharibi Asl, S. 2016. The oil and protein content of Isfahan's safflower in different periods of irrigation, levels of humic acid, and superabsorbent. International Journal of Life Science and Pharma Research. 1: 56-63.

Babec, B., Šeremešić, S., Hladni, N., Terzić, S., Vojnov, B., Ćuk, N., and Gvozdenac, S. 2020. Effect of intercropping sunflower with legumes on some sunflower morphological traits. Ratar. Povrt. 57 (2), 61-67.

Bacon, M. (Ed.). 2009. Water use efficiency in plant biology. John Wiley & Sons. Oxford, UK.

Barati, V., and Ghadiri, H., 2016. Effects of drought stress and nitrogen fertilizer on yield, yield components, and seed protein content of two barley cultivars. Journal of Crop Production and Processing. 6(20), 191-206.

Chamani, F., Tohidi Nejad, E., and Mohayeji, M. 2018. Effect of salicylic acid on morpho-agronomical traits of Guar (*Cyamopsis tetragonoloba* L.) under drought stress. Journal of Crop Ecophysiology. 12(4), 569-580.

Chen, S., Zhao, C-B., Ren, R-M., and Jiang, J. H .2023. Salicylic acid had the potential to enhance tolerance in horticultural crops against abiotic stress. Frontiers in Plant Science. 14:1141918.

Davodi, S., MirShakari, B., MirMahmoodi, T., Yazdan Seta, S., and Farah Vash, F. 2020. Effects of seed priming with salicylic acid and ascorbic acid on grain yield and yield components of sunflower under water deficit conditions. Iranian Journal of Seed Sciences and Research. 7(2), 253-264.

Ebrahimian, E., Seyyedi, S.M., Bybordi, A., and Damalas, C.A. 2019. Seed yield and oil quality of sunflower, safflower, and sesame under different levels of irrigation water availability. Agricultural Water Management. 218: 149-157.

El–Bially, M.E., Saudy, H.S., Hashem, F.A., El–Gabry, Y.A., and Shahin, M.G. 2022. Salicylic acid as a tolerance inducer of drought stress on sunflower grown in sandy soil. Gesunde Pflanzen. 74:603- 613.

Esmaeili, M., Madani, H., Majd Nassiry, B., Chavoshi, S., and Sajedi, N.A. 2023. Study of water stress effects on water use efficiency and drought tolerance of new Sunflower cultivars. Journal of Water Research in Agriculture. 36(4), 359-376.

Ghaffari, M., Andarkhor, S.A., Homayonifar, M., Kalantar Ahmadi, S.A., Shariati, F., Jamali, H., and Rahmanpour, S .2020. Agronomic attributes and stability of exotic sunflower hybrids in Iran. Helia. 43(72):67– 81.

Ghasemi, M., Jahanbin, S., Latifmanesh, H., Farajee, H., and Mirshekari, A. 2021. Effect of brassinolide foliar application on some physiological and agronomic characteristics of sunflower (*Helianthus annuus* L.) under drought stress conditions. Journal of Crop Production. 14(1), 31-48.

Ghendov-Mosanu, A., Popovici, V., Constantinescu (Pop), C.G., Deseatnicova, O., Siminiuc, R., Subotin, I., Druta, R., Pintea, A., Socaciu, C., and Sturza, R. 2023. Stabilization of Sunflower Oil with Biologically Active Compounds from Berries. Molecules. 28(8), 3596.

Gholinezhad, E., and Darvishzadeh, R. 2018. Estimates of variance components and heritability of grain yield and yield components in confectionary sunflower landraces in different levels of irrigation. Journal of Plant Productions (Agronomy, Breeding and Horticulture). 41(2), 29-40.

Hamzei, J., Nejafi, H., and Babaei, M. 2017. Effect of irrigation and nitrogen on agronomic parameters, yield, grain quality and, agronomic nitrogen use efficiency of sunflower (*Helianthus annuus* L.). Iranian Journal of Field Crops Research. 14(4), 686-698.

Hasanvand, M.S., Aynehband, A., Rafiee, M., Mojadam, M., and Rasekh, A., 2014. Effects of supplemental irrigation and super absorbent polymer on safflower yield and seed quality (*Carthamus tinctorius* L.) under dry-farming conditions. Bulletin of Environment, Pharmacology and Life Sciences. 3(12), 174- 185.

Hemati, A., Alikhani, H.A., Ajdanian, L., Babaei, M., Asgari Lajayer, B., and Van Hullebusch, E.D. 2022. Effect of different enriched vermicomposts, humic acid extract, and indole-3-acetic acid amendments on the growth of *Brassica napus*. Plants. 11 (2), 227.

Hossini, F., Meskarbashee, M., and Rahnama, A. 2024. The effect of foliar application of cytokinin and salicylic acid on yield and physiological characteristics of Sunflower under drought stress conditions. Journal of Plant Production Research. doi: 10.22069/jopp.2024.22633.3163

Hussain, M., Farooq, S., Hasan, W., Ul-allah, S., Tanveer, M., Farooq, M., and Nawaz, A .2018. Drought stress in sunflower: physiological effects and its management through breeding and agronomic alternatives. Agricultural water management. 201:152–166.

Jami, M. Q., Ghalavand, A., Modarres-Sanavy, S. A. M, Mokhtassi Bidgoli, A., Baghbani-Arani, A., and Namdari, A. 2018. Effect of manure, zeolite, and irrigation on soil properties and seed yield of sunflower (*Helianthus annuus* L.) Iranian Journal of Crop Sciences. 19(2): 151-167.

Javadi, H., Moosavi, S. G. R., Javad Seghatoleslami, M., Ebrahimi, A. R., and Kozegar, M. 2022. Effect of methanol Spraying on some morphophysiological characteristics, yield and yield components of Sunflower (*Helianthus annuus* L.) under drought stress conditions. Plant Productions. 45(1), 29-40.

Khalilvand Behrouzyar, E., and Yarnia, M. 2014. Can methanol foliar application improve the productive performance of sunflower under water deficit stress? International Journal of Biosciences. 5(2): 28-32.

Khalvandi, M., Siosemardeh, A., Roohi, E., and Keramati, S. 2021. Salicylic acid alleviated the effect of drought stress on photosynthetic characteristics and leaf protein pattern in winter wheat. Heliyon. 7(1), e05908.

Majdom, M. 2017. Effect of drought stress on physiological characteristics and seed yield of sunflower at different levels of nitrogen. Journal of Crop Production. 9(4), 121-136.

Moradi Ghahderijani, M., Sadat Asilan, K., and Modarres Sanavy, S. A. M. 2015. Effect of improvers application on seed yield and irrigation water use efficiency of sunflower (*Helianthus annuus* L.) under water deficit stress conditions. Iranian Journal of Crop Sciences. 17(2):115 -127.

Mousavi, S., Vafabakhsh, J., and Sadr Abadi Haghighi, R. 2010. Effect of water deficit on water use efficiency of canola (*Brassica napus* L.) cultivars in Mashhad conditions. Journal of Agroecology. 2(3), 486-491.

Movahhedi-Dehnavi M, Behzadi Y, Niknam N., and Mohtashami R. 2019. Salicylic acid mitigates the effects of drought and salinity on nutrient and dry matter accumulation of linseed. Plant Process and Function. 8 (31):31-44.

Pál, M., Janda, T., Majláth, I., and Szalai, G. 2020. Involvement of salicylic acid and other phenolic compounds in light-dependent cold acclimation in maize. International Journal of Molecular Sciences. 21(6), 19942.

Rauf, S., and Sadaqat, H.A. 2007. Effects of varied water regimes on root length, dry matter partitioning, and endogenous plant growth regulators in sunflower (*Helianthus annuus* L.). Journal of Plant Interactions. 2(1):41–51.

Rehman, S.U., De Castro, F., Aprile, A., Benedetti, M., and Fanizzi, F.P. 2023. Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. Agronomy. 13(4), 1134.

Seyed Sharife, R., and Seyed Sharife, R. 2019. Effects of different irrigation levels, methanol application, and nano iron oxide on yield and grain filling components of sunflower (*Helianthus annuus* L.). Crops Improvement (Journal of Agricultural Crops Production). 21(1): 27-42.

Smaeili, M., Madani, H., Majd Nassiri, B., Sajedi, N.A., and Chavoshi, S. 2022. Study of water deficiency levels on ecophysiological characteristics of sunflower cultivars in Isfahan, Iran. Applied Water Science. 12(5): 1-11.

Tadayon, M.R., Tadayyon, A., and Esmaili, S. 2021. Effect of humic acid on growth and yield indices of Sunflower (*Helianthus annuus*) in a saline soil. Journal of Crop Production and Processing. 11(3):101-110.

Wyszkowski, M., Kordala, N., and Brodowska, M.S. 2023. Trace element content in soils with nitrogen fertilisation and humic acid addition. Agriculture. 13(5), 968.

Zhanga, Y., Liua, G., Gaoa, Sh., Zhanga, Zh., and Huang, L. 2023. Effect of humic acid on phytoremediation of heavy metal contaminated sediment. Journal of Hazardous Materials Advances. 9(2023), 100235.