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Original Research

Study of the effects of different irrigation regimes on morphological and functional traits of sunflower cultivars

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ABSTRACT:

Nowadays increase of population and need for food and limitation of water resources have caused that the worth of this vital liquid to be cleared up more than ever. In order to determine the water requirement of sunflower cultivars, an experiment was conducted in 2015-2016 in Iran. The experiment was carried out in factorial randomized complete block design with four replications levels. The treatments was contained irrigation regimes (D_1: irrigation after 60 mm, D_2: irrigation after 120 mm, D_3: irrigation after 180 mm evaporation from evaporation pan, class A and sunflower cultivars) (H_1: Azargol, H_2: Prograss, H_3: Gabur, H_4: Hysan 25 and H_5: Hysan 36). Results showed that under non-stress and moderate stress conditions, Azargol and progress cultivars had the highest grain filling time, 1000 grain weight, stem diameter and head diameter. Under severe stress conditions, progress and Gabor cultivars excelled in some traits, so that Progress cultivar had the highest seed filling, 1000 grain weight, and stem diameter and Gabor cultivar had the highest number of budding, number of flowering and stem diameter. Results related to physiological traits showed that Azargol and Progress cultivars in terms of all studied traits (leaf area index, CGR, PGR, NAR and RWC) had a remarkable advantage over other cultivars. Under severe stress conditions, Azargol cultivar had the highest CGR, PGR, NAR and RWC. Considering that, the use of tolerant cultivars plays an important role in increasing the yield of sunflower. The present study suggested using Azargol cultivar for cultivation compared to other cultivars.

Keywords:

Drought stress, Morphological features, Physiological features, Leaf area index.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is a plant of Citrus family and considered as the fourth oilseed plant in the world. This plant is adaptable to a wide range of environmental conditions that can have an acceptable function in arid and semi-arid regions and due to its developed root system has high efficiency in water extraction from the soil, provided that the soil is deep and soil structure does not limit the root development (Nadeem *et al*., 2002). One of the main uses of this plant is sunflower oil, which, in addition to its nutritional use, is used to produce soap, high quality dyes and cosmetics. Sunflower stem's fiber and cellulose are widely used in paper and cellulose industries. In addition, sunflower seeds are used in poultry industry due to high protein content (17%). Sunflower stems and leaves can be used as silos for livestock feeding, as well as because these organs are rich in mineral elements, the return of sunflower plant residues to soil increases the organic matter and soil fertility as well as due to having phytotoxin materials, reduces weed density (Fulda *et al*., 2011; Yadollahi *et al*., 2014).

Given that sunflower highest area under cultivation in Iran is related to rainfed cultivation, it is necessary to recognize the cultivar(s) with high yield and minimum water consumption (Safavi *et al*., 2011). Regarding the limited resources of water and improper and dispersed distribution of rainfall in Iran, the optimal use of water in agriculture should be taken into account in order to provide the required food with the most efficient and productive water available. So in regions with no land limitation, increasing the area under cultivation finally will lead to more agricultural production. Low irrigation is one of the optimal water use methods, in which some water stress occurs during the growing season. The main purpose of low irrigation is mainly to increase water use efficiency with reducing the irrigation requirement of the plant and removing that part of irrigation water, which has no significant effect on increasing the yield (Saleem, 2003). Drought stress is one of the most common environmental stresses caused by disturbing the morphological and physiological processes which limits the plants and reduces the plant yield (Roche *et al*., 2009). Various studies have shown that the lack of moisture in soil is one of the most important limiting factors in sunflower fields and adequate moisture is an important factor in increasing yield and grain yield components (Hamrouni *et al*., 2001; Fulda *et al*., 2011).

The response of crop plants to available water shortages depends on the growth stage and intensity of the stress (Amiri *et al*., 2017). In addition to affect morphological traits negatively such as the plant height, stem diameter, head diameter, leaf area and functional traits such as 1000 grain weight, grain yield, number of seeds per head and dry weight of the plant, moisture stress affects photosynthetic traits. So that a significant reduction in photosynthesis can lead to the plant's dry matter reduction (Hosseinzadeh *et al*., 2016). In a study on sunflower, it was reported that irrigation regimes of more than 100 mm evaporation from class A evaporation pan was considered as water shortage stress and resulted in a significant reduction in morphological and functional traits compared to non-stress conditions (Khamari *et al*., 2007).

The percentage and yield of oil in this plant are directly related to morpho-physiological properties, so that under drought stress, a significant reduction in traits such as the plant height, leaf area, number of seeds per head, 1000 grain weight, total dry weight, absorption of nutrients and relative water content of the leaves result in significant reduction in essential oil and oil of these plants (Hamrouni *et al*., 2001). Studies on different cultivars of sunflower have shown that under conditions of water shortage, stable morphological and physiological indicators are important in increasing the yield components and oil content, so under water

Table 1. Chemical characteristics of soil

S. No	Characteristics of soil	2015		2016	
		Depth of soil (cm)		Depth of soil (cm)	
		0-30	30-60	0-30	30-60
1	EC ($ds.m^{-1}$)	5.36	5.1	5.44	5.32
2	pH	7.9	7.6	7.1	7.2
3	Nitrogen (%)	0.084	0.034	0.091	0.032
4	Phosphorous (ppm)	11.1	6.9	11.4	6.3
5	Potassium (ppm)	193	122	219	154
6	Clay (%)	31.1	30.09	31	31
7	Silt (%)	38	39	43	39
8	Sandy (%)	27	29	26	32
9	Organic materials (%)	1.08	0.89	1.1	0.87
10	Soil texture	Clay loam	Clay loam	Clay loam	Clay loam

shortage stress conditions, the cultivars that are capable of fewer changes in these indicators can be introduced as tolerant cultivars for cultivation.

Considering the conditions of sunflower rainfed cultivation and synchronization of drought stress during flowering stages, it is very necessary to identify tolerant cultivars that are more compatible with water shortage stress conditions. The purpose of conducting this study was to evaluate five cultivars of sunflower in different irrigation regimes based on morphological, physiological and functional properties to introduce a superior cultivar for cultivating in Isfahan in Iran.

MATERIALS AND METHODS

In order to examine the effects of irrigation regimes on functional and morphological properties of different cultivars of sunflower, an experiment was carried out in Isfahan Province for two years (2015-2016) in a research-extension field of Ardestan. The experimental design used for each year was considered as a split plot in a randomized complete block design with four replications. The research-extension field is located 22 km northwest of Ardestan in latitude of 52' and 14 min east and 33' and 32 min north and elevation 1050 m above sea level. The studied irrigation regimes included D_1: irrigation after 60 mm evaporation from the level of class A evaporation pan (normal conditions), D_2: irrigation after 120 mm evaporation (mild water shortage stress) and D_3: irrigation after 180 mm evaporation (intense water shortage stress).

The other studied factor was sunflower cultivar, including Azargol (H_1), Progress (H_2), Gabor (H_3), Hysan 25 (H_4) and Hysan 36 (H_5). Each experimental plot consisted of four 5 m rows and the time of application of irrigation regimes was after plant deployment and from six leaf stage in experimental plots. The spacing of the planting lines was 60 cm and the plant spacing was 20 cm on the rows. Irrigation treatments started from the six-leaf stage and continued until 10 days before the physiological maturity. To carry out this experiment, the soil was first irrigated to be soft for plowing. Then, at the beginning of May, the land was plowed and in July the samples were taken from the soil at depths of 0-30 and 30-60 cm. The results of soil physicochemical properties in the experimental site are presented in Table 1.

According to soil test results, about 50 kg net nitrogen, 60 kg of pure potassium from potassium

Table 2. Means comparison of morphological characteristics of Sunflower cultivars under different irrigation regimes

S. No	Irrigation	Sunflower cultivars	Plant height (cm)	Budding period (Days to Budding)	Flowering period (Days to flowering)	1000 grain weight (gr)	Stem diameter (cm)	Head diameter (cm)
		H_1	173.2f	33.86 c	46.67 bc	66.09 a	2.38 a	22.46 b
		H_2	165.1i	34.07 bc	46.63 bc	61.23 b	2.43 a	23.18 a
1	D_1	H_3	175.6 e	37.03 a	47.41 ab	47.8 c	1.76 fg	21.45 de
		H_4	183.7 a	34.28 bc	48.41 a	58.45 cd	1.83 f	19.04 i
		H_5	177.3 d	30.75 f	43.94 gh	46.01 h	1.71 gh	15.79 l
		H_1	169.7 h	32.52 d	45.64 cde	60.74 b	2.26 b	22.16 bc
		H_2	164.4 i	31.82 de	45.89 cd	58.71 c	2.38 a	20.84 fg
2	D_2	H_3	171.7 g	34.74 b	45.84 cde	45.13 h	1.77 fg	21.13 ef
		H_4	181.6 b	32.5 d	46.66 bc	54 e	1.77 fg	18.21 j
		H_5	175.5 c	28.42 g	41.95 i	42.42 i	1.66 h	14.64 m
		H_1	170.6 h	31.11ef	44.15fgh	58.28 cd	1.74 fgh	21.74 cd
		H_2	163.1 j	31.43 ef	43.49 h	57.11 d	2.03 de	19.97 h
3	D_3	H_3	173.6 f	33.66 c	45.09def	41.78 i	2.08 cd	20.52 g
		H_4	180.8 b	31.13 ef	44.78 efg	49.99 f	1.7 fg	18.62 ij
		H_5	171.2 f	27.95 g	41.26 i	39.57 j	1.61 h	14.08 m
4	LSD%	-	1.03	0.76	1.06	1.39	0.09	0.49

Difference between data of each column followed by the same letter was not statistically significant ($P<0.05$)

sulfate source and 150 kg of pure phosphorus from super phosphate source were added to the soil and then the land was ploughed and after preparation, cultivation was carried out manually on both sides. Irrigation was carried out for up to six leaves every 10 days. In order to determine the amount of irrigation water required for each plot, using the following equation (Hashemi *et al*., 1995), the volume of water consumed in each treatment was calculated:

$$V = \frac{(FC - \theta m) \times \rho b \times DRoot \times A}{Ei}$$

V: irrigation water volume in cubic meter; FC: field capacity; Ɵm: percentage of moisture content before irrigation; pb: soil weight in grams per cubic centimeter; A: irrigated area in square meters; D_{root}: depth of root development in meters; Ei: irrigation efficiency.

The plant maturity was determined by checking the seeds. The full maturity stage was considered when the seeds were full, browned behind the head and petals and leaves were dried. The studied morphological traits included the plant height, budding, flowering, grain filling period, number of seeds per head, stem diameter and head diameter, which were measured based on common methods. The leaf area index was measured using the method NeSmith (1992) and based on the following equation.

$$LAI = 0.655(L \times W) - 0.00011(L \times W) 2$$

LAI: Leaf Area Index, L: Leaf length, W: Leaf width

In order to measure 1000 grain weight, 200 seeds were selected from each experimental treatment and their weight was determined. Finally, for each replication, the following equation was used to determine the weight of 1000 grains:

$$1000 \text{ grain weight} = \frac{\text{Counted seed weight}}{\text{Number of counted seeds}} \times 1000$$

In order to measure the biological yield of each treatment, the shoot was isolated from the plant and

Table 3. Means comparison of yield components of sunflower cultivars under different irrigation regimes

S. No	Irrigation	Sunflower cultivars	Leaf area index (cm)	Total dry weight (gr)	Biological yield (gr/m^2)	Grain yield (Kg/ ha)	Harvest index	Oil yield (Kg/ ha)
1	D_1	H_1	1.56 a	2003 a	12316 a	5550 a	49.27 a	347.2 a
		H_2	1.45 b	1819 c	11698.2 b	4972 d	42.5 f	318.1 c
		H_3	1.35 c	1810.2 c	11623.3 b	4934.7 d	42.46 f	307.3 d
		H_4	1.13 d	1671.2 d	10798.8 e	4742.6 f	43.92 e	299.3 e
		H_5	1.53 a	1911 b	10815.4 de	4748.3 f	43.90 e	292.8 f
2	D_2	H_1	0.97 e	1496 e	10909.8 c	5375 b	45.08 d	327.1 b
		H_2	0.58 gh	1476.2 e	10921.6 c	4877.3 e	44.66 d	282.3 g
		H_3	0.58 gh	1510.1 e	10936.8 c	4648.7 g	42.50 f	285.1 g
		H_4	0.55 hi	1477 e	9978 h	4260.3 j	42.70 f	259.5 h
		H_5	0.65 fg	1448 ef	9831 i	4318.8 j	43.92 e	259 h
3	D_3	H_1	0.48 ij	1386.3 fg	10730.7 ef	5072 c	47.28 b	288.1 g
		H_2	0.45 jk	1306 h	10677.7 f	4431.4 h	41.50 g	249.4 i
		H_3	0.39 k	1321 gh	10197.2 e	4033.5 l	39.56 h	232.7 j
		H_4	0.43 jk	1302 h	9472.6 j	4357.8 i	46.01 c	215.7 k
		H_5	0.72 f	1362 gh	9443.3 j	4138.5 k	43.82 e	211.1 k
4	LSD%	-	0.07	77.84	10.2	54.7	1.4	5.67

Difference between data of each column followed by the same letter was not statistically significant (P<0.05).

dried in the oven for 48 h and then weighed by a digital scale with a precision of 0.001 g. Total dry weight of each treatment was determined by measuring total plant weight. In order to determine the grain yield, after separating seeds from the shoot, the seeds were dried in oven at 80°C for 48 h and then their weight was determined. Harvest index was obtained from grain yield to biological yield ratio in each experimental treatment and expressed as percentage. In order to determine the percentage of seed oil, from seeds obtained from each plot, a 10 g sample was isolated and its oil percentage was determined by Soxhlet method and Soxhlet apparatus using non-polar solvent hexane (Eyvazzadeh *et al*., 2010). The oil yield was also obtained from multiplication of oil percentage in grain yield.

The crop growth rate, relative growth rate and net-assimilation rate were measured by the following equations.

Crop Growth Rate: $$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Relative Growth Rate: $$RGR = \frac{LnW_2 - LnW_1}{t_2 - t_1}$$

W_1: Dry weight of the plant at the start of treatment; W_2: Dry weight of the plant at the end of treatment; t_1-t_2: Time between the beginning and end of treatment

Net Assimilation Rate:

NAR= CGR/LAI

CGR: Crop Growth Rate,

LAI: Leaf Area Index

Measurements of relative water content

For the measurement of RWC healthy and developed leaves were harvested and weighed to

Table 4. Means comparison of physiological traits of sunflower cultivars under different irrigation regimes

S. No	Irrigation	Sunflower cultivars	Relative Growth Rate (RGR)	Crop Growth Rate (CGR)	Net Assimilation Rate (NAR)	Seed oil (%)	Relative water content (RWC)
1	D_1	H_1	0.00027 a	0.72 a	0.48 b	53.62 ab	58.60 a
		H_2	0.00024 b	0.42 c	0.58 a	63.95 a	55.18 b
		H_3	0.00021 c	0.44 c	0.32 de	62.24 ab	58.44 a
		H_4	0.00018 d	0.36 d	0.31 de	63.07 ab	49.97 cd
		H_5	0.00022 c	0.61 b	0.39 c	61.63 ab	51.19 c
2	D_2	H_1	0.00012 de	0.56 b	0.29 e	60.82 ab	47.73 de
		H_2	0.00012 de	0.21 e	0.36 cd	57.85 abc	44.77 f
		H_3	0.00012 de	0.21 e	0.36 cd	61.28 ab	46.79 ef
		H_4	0.00012 de	0.19 ef	0.34 de	60.85 ab	44.29 f
		H_5	0.00013 d	0.22 e	0.34 de	59.97 ab	44.81 f
3	D_3	H_1	0.00013 d	0.11 gh	0.23 f	56.78 abcd	36.28 g
		H_2	0.00011 e	0.07 h	0.15 g	56.24 bcd	33.94 g
		H_3	0.00011 e	0.07 h	0.17 g	57.65 abc	35.63 g
		H_4	0.00011 e	0.07 h	0.16 g	49.42 d	30.26 h
		H_5	0.00012 de	0.14 fg	0.19 fg	50.96 cd	29.85 h
4	LSD%	-	1.7	0.039	0.05	7.66	2.54

Difference between data of each column followed by the same letter was not statistically significant (p<0.05)

determine the Fresh Weight (FW). Thereafter, leaves were immersed in distilled water for 48 h to determine Turgor Weight (TW). Next, the leaves were dried in an oven at 70°C for 48 h and their DW was calculated (Karimi and Siddique, 2015)

LWC (%) = (FW-DW/TW-DW) × 100

Statistical analysis

All data were statistically analyzed using factorial ANOVA test (MSTAT-C Version 4). Duncan's multiple range tests by using MSTAT-C software was performed to confirm the variability of results and for the determination of significant (P≤0.05) difference between treatment groups.

RESULTS AND DISCUSSION

Morphological traits

The results of data variance analysis showed that irrigation treatments and sunflower cultivars had a significant effect on the plant height, budding period, flowering period, grain filling period, 1000 grain weight, stem diameter and head diameter. The mean comparison of data on interactions of cultivar × irrigation on the plant height showed that, under normal irrigation conditions, H_{25} with 183.7 cm had the highest amount of this trait, which in comparison with other levels under these conditions increased significantly. Under severe and moderate stress conditions, H_{25} cultivar had the highest plant height with 181.6 and 180.8 cm, respectively, which increased significantly compared to other levels. In all irrigation regimes, the lowest plant height was related to progress cultivar (H_2), which had a significant reduction at all levels of irrigation regime compared to other cultivars (Table 2).

The mean comparison of data in studying interactions between cultivar × irrigation on the stem diameter showed that under no stress conditions, Azargol (H_1) and Progress (H_2) cultivars had a significant increase in the stem diameter compared to other levels. The lowest amount of this trait under no stress conditions was also related to Hysan 36 (H_5), which did not have a significant difference with Gabor cultivar. Under moderate stress conditions, Progress cultivar had the highest stem diameter, which increased significantly compared to other cultivars. The lowest stem diameter under non-stress conditions was related to Hysan 36, which had a significant reduction compared to other cultivars. Under severe stress conditions, the highest stem diameter belonged to Gabor cultivar, which did not have a significant difference with Progress cultivar. Under these conditions, the lowest stem diameter was observed in Hysan 36 cultivar, which had a significant reduction compared to other cultivars (Table 2). In examining interactions between cultivar × irrigation on the head diameter, the results showed that under non-stress conditions, the highest and lowest diameter were related to Progress and Hysan 36 cultivars respectively, which had a significant difference compared to other cultivars. Under moderate and severe stress conditions, the highest diameter was found in Azargol cultivar, which increased significantly compared to other cultivars. The lowest amount of this trait was related to Hysan 36 under severe and moderate stress conditions, which had a significant reduction compared to other cultivars (Table 2).

One of the main effects of water shortage stress on plants is reduced shoot growth such as the plant height, dry weight, number of leaves and stem diameter, the main reasons of which are a reduction in hormonal secretion, an increase in growth inhibitors, cell division reduction, stomata closure and reduction in photosynthesis, plant growth period shortening and stress-free mechanisms (Bayoumi *et al*., 2008; Hosseinzadeh *et al*., 2016). Studies have shown that higher plant under drought stress indicates better growth of tolerant cultivars and better tolerance of water shortage conditions (Rahbarian *et al*., 2011; Ahmadpour *et al*., 2016). Reduced plant height has also been reported under conditions of water shortage in soil in other plants including pea (Gamze *et al*., 2005), maize (Barens and Wooley, 2009), peanut (Vorasoot *et al*., 2003) and lentil (Ahmadpour *et al*., 2016). Under drought stress, lack of maintenance of turger pressure (cellular inflammation), allocation of more synthesized materials to cope with stress and shortening the growth period of the plant can prevent the normal development of cells and consequently, reduce the height and diameter of the stem (Cox and Jolliff, 2000; Sikder *et al*., 2015). Reducing the diameter due to water shortages can be explained by the fact that the head flower grows gradually during flowering, and each day a few layers of the flower begin to open from the outside to the inside, great part of diameter is formed at pollination stage, because at this stage the cultivars are faced with water shortages and lack of maintenance of torque pressure, as a result the cells are not normally developed and, and less expanded (Goksoy *et al*., 2004).

The mean comparison of interactions between irrigation regimes and sunflower cultivars on budding period showed that in all three irrigation regimes (non-stress, moderate and severe stress), Gabor cultivar had the highest amount of budding period compared to other cultivars examined that this increase was significant. The lowest amount of this trait was observed in all three irrigation treatments in Hysan 36, which had a significant reduction compared to other cultivars (Table 2). The mean comparison of data of irrigation × cultivar effects on flowering period showed that Hysan 25 cultivar had the highest flowering period under non-stress conditions, which had a significant increase compared to other levels except for Gabor cultivar. Under moderate stress conditions, Hysan 25 cultivar had the highest flowering period but showed no significant difference with other cultivars except for Hysan 36.

Under severe stress conditions, Gabor cultivar had the highest amount of this trait, which was not significantly different from Azargol and Hysan 25 cultivars. At all irrigation levels, Hysan 36 cultivar had the lowest flowering that reduced significantly in comparison with other cultivars (Table 2). The results of the mean comparison of irrigation × cultivar effects on grain filling period showed that at all irrigation levels (non-stress, moderate and severe stress), the highest grain filling period was observed in Progress cultivar compared with other cultivars studied at each level of irrigation increased significantly. The lowest amount of this trait was observed in Hysan 36 in all irrigation regimes, which had a significant reduction compared to other cultivars (Table 2). The results of Table 3 in relation to 1000 grain weight indicate that Azargol cultivar had the highest 1000 grain weight under non-stress and moderate stress conditions, which increased significantly at these irrigation levels compared to other cultivars. Under severe stress conditions, Azargol and Progress cultivars compared to other cultivars had a significant increase in 1000 grain weight. The lowest 1000 grain weight at all irrigation levels belonged to Hysan 36 cultivar, which had a significant reduction compared to other cultivars (Table 2).

At budding, flowering and filling stages of sunflower seeds, water shortage reduces the reservoir's ability to absorb photosynthetic materials affecting reducing the number of buds, flowers and seeds. On the other hand, under such conditions, the plant tried to extend its life in a shorter period of time (stress-free mechanisms) which, using these mechanisms also reduces the number of buds, flowers and seeds in the sunflower (Khamari *et al*., 2007). Several other reports have indicated that drought stress affecting the plant growth and reproduction organs, can affect reducing the plant's final yield and the plant tries to complete growth in a short period of time in order to pass the critical conditions (Razi and Asaad, 1998; Goksoy *et al*., 2004).

In a study on sunflower, it was observed that drought stress accelerated physiological maturity and reduced duration of the grain filling period, which is consistent with the results of this study (Roshdi *et al*., 2006). The synchronization of grain filling period with moisture stress in stress treatments and shortening of this period is due to the reduced leaf area and some morphological properties such as number of leaves, number of seeds per head, reduction of area according to the main factor of weight reduction in 1000 grain weight (Karimzaded-Asl *et al*., 2003).

Yield and yield components

The mean comparison of data showed that Azargol and Hysan 36 cultivars had the highest leaf area index under non-stress conditions which had a significant increase compared with other cultivars. The lowest amount of this trait was observed in Gabor cultivar, which had a significant reduction compared to other cultivars. Azargol cultivar had the highest level of leaf area under moderate stress conditions, which increased significantly in comparison with other cultivars. Under severe stress conditions, Hysan 36 had the highest amount of this trait, which increased significantly compared to other cultivars. The lowest leaf area index under these conditions was related to Gabor cultivar, which did not have a significant difference with Progress and Hysan 25 cultivars (Table 3). Leaf area index is a significant quantity for showing the plant's growth status under environmental stress conditions (Naderi *et al*., 2005; Hosseinzadeh *et al*., 2011). The greater leaf area of a plant exhibits more photosynthetic capacity as a secondary source for photosynthetic material storage (Amiri *et al*., 2017).

It has been proven that the reduction in water in the planting bed has a direct effect on the reduction in the level and number of leaves (Gunes *et al*., 2006). In this study, water stress levels in comparison to non-stress conditions reduced leaf area index in all studied cultivars. Increasing morphological properties of leaves in water shortage tolerant cultivars is a reason for resistance and superiority to sensitive cultivars, so that the negative impact of water shortage stress was not actual (Guerfel *et al*., 2008). Reducing the number and area of leaves during water stress is associated with early aging, which is a factor in reducing transpiration and early plant maturity under water shortage stress condition (Gunes *et al*., 2006). Adequate moisture increases the growth properties of the shoot and root, so that with reducing soil moisture, the development of the root system is limited to the upper layers of the soil and leads to premature aging in leaves and roots, these conditions reduce the plant height, number and area of leaves (Wang *et al*., 2003; Amiri *et al*., 2017).

The results of Table 4 showed that Azargol cultivar had the highest dry weight under non-stress conditions, which increased significantly compared to other treatments. The lowest amount of this trait was observed in Gabor cultivar, except for Progress cultivar that significantly reduced compared to other cultivars. No significant difference was found between treatments under moderate stress conditions. However, under severe stress conditions, Azargol cultivar had the highest dry weight, which was not significantly different from that of Gabor and Hysan 36 cultivar (Table 3).

The results showed that Azargol cultivar had the highest biological yield under non-stress conditions, which increased significantly compared to other treatments. Under these stress conditions, the lowest biological yield was related to Hysan 25, which did not have significant difference with Hysan 36. Under moderate stress conditions, Azargol, Progress and Gabor cultivars were significantly increased compared to Hysan 25 and Hysan 36 cultivars. Under severe stress conditions, Azargol and Progress cultivars showed a significant increase in biologic yield compared to other cultivars (Table 3).

Several studies have reported that reducing available water in soil reduces compressive potential needed for cell development, which affects the growth rate and cell division of the plant (Heidari and Karami, 2013). On the other hand, under conditions of water shortage stress, in addition to degradation of photosynthetic pigments, reduction in efficiency of photocysteine II and leaf area, CO_2 does not enter stomata cells and leads to a reduction in pure photosynthesis by about 50%.). The most important reasons for a significant reduction in biological yield under conditions of mild and severe water shortage stress are reduced leaf area and duration, activity of cycline kinases, cell division, stomata closure, reduced photosynthesis and consequently growth inhibition (Mirshekari *et al*., 2012).

The means comparison showed that Azargol cultivar significantly increased grain yield under non-stress conditions compared to other cultivars. The lowest grain yield was observed in Hysan 25 and Hysan 36 cultivars, which was significantly different from other cultivars. Under moderate water stress conditions, Azargol and Hysan 25 cultivars had the highest and lowest grain yield respectively, which was significantly different from other cultivars. Under severe stress conditions, Azargol cultivar had the highest grain yield, which showed a significant increase compared to other cultivars, but the lowest amount of this trait was observed in Gabor cultivar, which showed a significant reduction compared to other cultivars (Table 3). The mean comparison of data showed that Azargol cultivar significantly increased harvest index under non-stress conditions compared to other cultivars.

The lowest harvest index was related to Hysan 25 and Hysan 36 cultivars, which had a significant reduction compared to other cultivars. Under moderate stress conditions, the highest harvest index was observed in Azargol cultivar, which did not have a significant difference with Progress cultivar. The lowest amount of this trait was observed in Hysan 36 cultivar, which had a significant reduction compared to other cultivars. Under severe stress conditions, the highest and lowest harvest index was related to Azargol and Gabor cultivars respectively, which showed a significant difference compared to other cultivars (Table 3). It has been reported in several studies that water shortage in sunflower planting bed, especially during flowering and seed production, led to a reduction in grain yield and 1000 grain weight (Goksoy *et al*., 2004; Erdem *et al*., (2006). Water shortage stress at vegetative stage by reducing the plant leaf development and photosynthetic level and at reproductive stage by reducing the number of flowers, number of seeds per head and grain filling period reduced the functional traits such as 1000 grain weight and grain yield (Heidari and Karami, 2013). Harvest index is a measure of seed weight / plant ratio, and high yielding cultivars have a higher harvest index. Considering the direct relationship between grain yield and harvest index, a significant reduction in harvest index at stress levels seems logical (Khamari *et al*., 2007). In some studies, the most important reason for a significant reduction in harvest index under water stress conditions was reduced nutrients' transfer to seeds and severe grain yield reduction (Karimzaded-Asl *et al*., 2003; Roshdi *et al*., 2006). On the other hand, the sharp reduction in the number of heads, number of seeds per head and 1000 grain weight (important traits in determining grain yield) under water shortage stress conditions are other important reasons for the significant reduction in harvest index.

The results showed that Azargol cultivar had the highest oil yield under non-stress conditions, which showed a significant increase compared to other cultivars. The lowest oil yield was observed in Hysan 36 cultivar, which had a significant reduction compared to other cultivars. Under mild and severe stress conditions, it was observed that Azargol cultivar caused a significant increase in oil yield compared to other treatments. Hysan 25 and Hysan 36 cultivars significantly reduced oil yield compared to other cultivars (Table 3). Oil yield is the major economic result of sunflower planting and one of the most important traits in selecting water shortage tolerant cultivars of this plant, so that cultivars with higher seed and oil yields under water stress conditions are introduced as resistant cultivars for cultivation (Daneshian and Jabbari, 2009; Safavi *et al*., 2011). Under water shortage conditions, a reduction in seeds' yield, seeds' capacity for oil accumulation and seed oil content are one the most important reasons for a significant reduction in oil yield (Demirtas *et al*., 2010). In some studies, it was observed that a positive and significant correlation was found between seed yield and oil yield, so that with a significant reduction in seed yield under drought stress, oil yield reduced significantly (Safavi *et al*., 2011; Heidari and Karami, 2013).

Physiological traits

The mean comparison of relative growth rate (RGR) in sunflower cultivars showed that Azargol cultivar had the highest relative growth rate under non-stress conditions, which increased significantly compared to other cultivars. The lowest amount of this trait was related to Gabor and Hysan 36, which did not show any significant difference. No significant difference was found between cultivars under moderate stress conditions. Under severe stress conditions, Azargol cultivar showed the highest relative growth rate with a significant difference with other cultivars except for Hysan 36. The lowest amount of this trait was observed in Progress, Gabor and Hysan 25 cultivars, which did not show a significant difference (Table 4). The mean comparison of interactions between irrigation and cultivar on Crop Growth Rate (CGR) showed that Azargol cultivar had a significant increase in CGR under non-stress and moderate stress conditions.

The lowest amount trait was observed under non -stress conditions in Progress and Gabor cultivars, which had a significant reduction compared to other varieties. Under moderate stress conditions, the lowest CGR was observed in the cultivars Progress, Gabor and Hysan 36, which had a significant reduction compared to other cultivars. Under severe stress conditions, Hysan 36 cultivar had the highest CGR with a significant difference with other cultivars except for Azargol cultivar. Under these conditions, Progress, Gabor and Hysan 25 cultivars significantly reduced CGR compared to other cultivars (Table 4). The mean comparison of net -assimilation rate (NAR) in irrigation × cultivar interaction indicated that under non-stress conditions, Progress cultivar of sunflower had the highest NAR, which increased significantly compared to other cultivars. The lowest amount of this trait was also observed in Hysan 25 cultivar, which was not significantly different from Gaboor cultivar. Under severe stress conditions, Azargol cultivar significantly increased this trait with a significant difference with other cultivars except Hysan 36.

The lowest NAR was in Progress, which did not differ significantly from Gabor, Hysan 25 and Hysan 36 (Table 4). RGR and CGR are important physiological indicators to evaluate resistance of plants to environmental stresses such as drought, salinity, heat, etc (Xu *et al*., 2009). The CGR in fact determines the development of tissue, its stability determines the amount of dry matter produced, and PGR indicates the accumulation of dry matter per unit time (Karimi and Siddique, 1991). These indicators are directly proportional to dry matter of the plant. Therefore, reducing dry matter under drought stress has a direct effect on relative growth rate and growth rate of the crop (Karimi and Siddique, 1991). In this regard, several studies have shown that under drought stress, with stomata closure, the amount of pure photosynthesis and nutrients significantly reduced, and under such conditions, plants rather than spend energy to produce nutrients and increase the amount of dry matter, transfer and distribute existing nutrients (Xu *et al*., 2009; Soleymanifard *et al*., 2011). The study results showed that in all studied cultivars, water shortage stress caused a significant reduction in the indicators.

The mean comparison of data of irrigation × cultivar interaction on leaf relative water content showed that under non-stress conditions, Azargol and Gabor cultivars had the highest relative water content, which was significant compared to other cultivars. The lowest amount of this trait was observed in Hysan 25 cultivar, except for Hysan 36 with a significant difference with other cultivars. Azargol cultivar had the highest relative water content under mild stress conditions, which increased significantly compared to other cultivars. Under severe stress conditions, the highest relative leaf water content was observed in Azargol cultivar, which did not show a significant difference with Progress and Gabor cultivars. The lowest amount of this trait was observed in Hysan 36, which did not show a significant difference with Hysan 25 (Table 5). The relative water content of leaf has been introduced as an important index in determining the tolerance of genotypes to drought stress. Several studies have shown that high relative water content in a plant under water stress conditions indicates that the plant tolerates to the condition (Rahbarian *et al*., 2011; Yordanov *et al*., 2003). Preserving leaf water by reducing evapotranspiration is an important mechanism for avoiding drought stress. Various studies have shown that the water retaining capacity of leaf under water shortages stress conditions reduced in sensitive cultivars (Beck *et al*., 2007; Amiri *et al*., 2017). Water shortage stress resistant cultivars have mechanisms to preserve leaf water and prevent its loss. One of these mechanisms is the reduction in leaf area in order to reduce surface evaporation and transpiration, as well as regulation of opening and closing of stomata under these conditions (Hosseinzadeh *et al*., 2016). The difference between different cultivars in terms of relative water content of leaf is related to their difference in water absorption from soil, root system efficiency, and control power of water loss through the stomata (Galle *et al*., 2002). In maize, bean, pea and wheat, relative water content of leaf has been introduced as a marker for identifying drought stress tolerant genotypes (Galle *et al*., 2002; Helal and Samir, 2008; Hosseinzadeh *et al*., 2017; Rasti *et al*., 2014).

CONCLUSION

The study results showed that, in relation to morphological properties under non-stress and moderate stress conditions, Azargol and Progress cultivars had the highest grain filling time, 1000 grain weight, stem diameter and head diameter. Under severe stress conditions, Progress and Gabor cultivars excelled in some traits, so that Progress cultivar had the highest seed filling, 1000 grain weight, and stem diameter and Gabor cultivar had the highest budding, flowering and stem diameter.

In relation to physiological properties, the results of the present study showed that under non-stress conditions, Azargol and Progress cultivars in terms of all studied traits (leaf area index, CGR, PGR, NAR and RWC) had a remarkable advantage over other cultivars. Azargol cultivar had the highest leaf area index, CGR and RWC under moderate stress conditions. Under severe stress conditions, Azargol cultivar had the highest PGR, RGR, NAR and RWC. According to the study results and given that sunflower cultivation is usually carried out in rainfed fields (with drought stress), so the use of tolerant cultivars plays a significant role in increasing yield sunflower seeds. The present study suggests using Azargol cultivar for rainfed cultivation compared to other cultivars.

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