Effects of drought stress on grain qualitative traits in Iranian confectionary sunflower (*Helianthus annuus* L.) landraces

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ABSTRACT

This research was carried out to evaluate the effect of drought stress on grain yield and qualitative traits in some Iranian landraces of confectionary sunflower. Fifty six confectionary sunflower landraces were evaluated using three different water treatment conditions with three separate rectangular 7 × 8 lattice design with two replications. Irrigation treatments were as follows optimum irrigation, moderate and severe drought stress, where irrigation was carried out after the depletion of 50%, 70% and 90% of available water, respectively. The results of combined analyses showed that the main effect of irrigation treatments, genotypes and interactions between genotype and irrigation treatments was significant on oil and protein percentages, grain, oil and protein yield. The highest grain oil and protein yield were obtained from "Anghane 4" under the optimum irrigation condition. In contrast, in moderate and severe stresses, "Garaghoz 1" and "Salmas-Sadaghian" produced higher grain, oil and protein yield than other landraces. Based on the stress tolerance index (STI) and geometric mean productivity (GMP) indices, landraces 2, 7 and 12 were tolerant to drought stress, while landraces 36 and 37 with the lowest STI and GMP were sensitive to drought stress.

Keywords: Confectionary sunflower, Drought stress, Landrace, Oil percentage, Protein percentage.

INTRODUCTION

Drought stress is one of the most important and widespread environmental stresses which limits agricultural products and decreases the production efficiency in semi-arid and rain-fed regions (Farahvash *et al*., 2011). Sunflower (*Helianthus annuus* L.) as a source of vegetable oil and proteins is grown in many parts of the world. It is the fourth important vegetable oil crop (Vollmann and Rajcan, 2009). In regions where water scarcity is the principal limiting factor for cultivation, farmers are interested in planting crops that are able to adopt to drought stress conditions (Bannayan *et al*., 2008). Drought stress is one of the major causes for crop loss worldwide, reducing average yields by 50% and over (Wang *et al*., 2003). Under such stresses, water deficit in plant tissues develops, thus leads to a significant inhibition of photosynthesis (Pandey *et al*., 2012). Water stress adversely affects plant establishment and thereafter growth and development (Heidari and Karami, 2013). Environmental factors during the flowering stage and even at the seed filling period can widely affect grain yield and seed quality of oilseed crops (Ali *et al*., 2009). Heidari and Karami (2013) indicated that by increasing drought stress, grain yield significantly decreased. Stone *et al*. (2001) declared that drought stress causes considerable decreases in the yield and the oil content of sunflower. Tabatabaei *et al*. (2012) showed that drought stress significantly affects yield, yield components and qualitative traits. Mirshekari *et al*. (2012) declared that the limited irrigation stress resulted in the

Table 1. Chemical and physical properties of farm soil at depth of 0-30 cm.

Soil texture	Soil density g/cm^3	Electrical conductivity (ds/m)	pH	Percentage of saturation (%)	Lime (%)	Clay (%)	Silt (%)	Sand (%)	Carbon organic (%)	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)
Clay loam	1.4	0.8	8	47	17	35	37	28	1.2	0.12	12	375

reduction of grain yield and it occurred due to the limited vegetative and reproductive development. Bakht *et al*. (2010) demonstrated that the maximum oil content is produced in well-watered treatment and they found a positive correlation between oil yield and oil percentage with grain yield. Ebrahimian *et al*. (2011) stated that drought stress causes a decrease in grain yield, oil percentage and oil yield in sunflower. Drought stress caused a significant decrease in protein content compared to control (Hassan *et al*., 2010). Amrutha *et al*. (2007) stated that proteins are altered in plants growing under water stress compared to plants growing under non-stressed conditions. Several selection indices such as GMP and STI were used for screening drought tolerant genotypes (Fernandez, 1992). Khodarahmpour *et al*. (2011) and Khalili *et al*. (2012) reported that STI and GMP indices were more accurate criteria for selecting heat tolerant and high yielding genotypes. The response of confectionary sunflower accessions to water limitation is not properly investigated. The aim of the present study was to determine the effect of drought stress on grain yield, oil and protein contents and oil and protein yield in 56 Iranian confectionary sunflower landraces grown in west Azerbaijan, Iran.

MATERIALS AND METHODS

Study sites

In order to evaluate the effect of drought stress on grain, oil and protein yield as well as oil and protein percentages, an experiment was carried out in the experimental field of West Azerbaijan Agricultural and Natural Resources Research Center, Urmia, Iran in 2012.

For determining soil moisture, soil samples were taken from 2 depths of soil; 0-30 and 30-60 cm in each. Then weight moisture percentage was determined by the pressure plate (armfield CAT. REF: FEL13B-1 Serial Number: 6353 A 24S98). The field capacity of soil based on the method of Chen *et al*., was determined to be 26 with permanent wilting point of 14 (Chen *et al*., 2009). The soil physical and chemical properties of the experimental area are presented in Table 1.

Experimental design and treatments

The 56 confectionary sunflower landraces were evaluated with three different irrigation treatments in three rectangular 7 × 8 lattice designs with two replications. Irrigation treatments were optimum irrigation, moderate and severe drought stress where irrigation treatments were done after depletion of 50%, 70% and 90% of available water, respectively.

Irrigation treatments application

In order to obtain the correct irrigation time, soil was sampled by auger from the root development depth (30 cm) in each treatment, 48 hours after irrigation to measure soil weight moisture. Based on the measurements, the irrigation time was determined to be at soil weight moisture of 20, 17.6 and 15.2. To implement the irrigation operation, water usage volume was calculated by the following equation 1:

$$V = \frac{(fc - \theta m) \times \rho \times Droot \times A}{Ei}$$

where: V = irrigation water volume (m^3), θm = moisture soil weight after irrigation, A = irrigated area (m^2), FC = field capacity, ρ = soil density (g/cm^3), $Droot$ = root development depth (m) and Ei is the irrigation efficiency that was considered 90%. Therefore, the required water volume in each stage of irrigation in each treatment was calculated and distributed equally based on the water distribution efficiency of 90 percent by the flume and chronometer.

Studied characters

The final harvesting was carried out from two middle lines of planting in an area equal to 3.6 m^2. Final measurements were performed from these samples. Grains

Table 2. Combined analysis of variance for different traits in confectionary sunflower landraces grown under different water treatment conditions.

Source of variation	DF	Grain yield	Protein percent	Protein yield	Oil percent	Oil yield
Water status	2	46277099.58**	46.26**	1007353.86**	1003.67**	10596380.08**
Replication (Water status)	3	540221.39	1.48	12904.58	1.37	75509.11
Block (Water status × Replication)	42	507269.85**	1.23**	14498.47**	4.26**	82784.32**
Genotype	55	1380455.49**	7.06**	41995.47**	15.70**	214761.65**
Water status × Genotype	110	298849.20*	0.83 **	9090.01*	4.55**	47119.89*
Error	123	213565.1	0.05	6306.77	0.104	32794.98
C.V. (%)	-	22.58	1.37	23.25	0.84	22.73

**, * and ns: significant at the 1%, 5% probability levels and non significant, respectively.

were placed in the oven at 72°C for 48h. Oil contents were determined by the Soxhlet fat extraction method (Gajians and Koutroba, 1998). Seed protein content was determined by measuring the nitrogen content with the Micro-Kjeldhal (Model V40) method and multiplying it by 6.25 to express the total protein content (Bremner, 1996). In addition, oil yield was calculated by multiplying oil percentage by grain yield and dividing it by 100 (Inamullah *et al*., 2013). Protein yield was calculated by multiplying protein percentage by grain yield and dividing it by 100 (Karadogan and Akgun, 2009). Using the grain yield of genotypes in well-watered and water-stressed conditions, drought tolerance indices were calculated.

Statistics

Analysis of variance was performed using PROC GLM in the SAS 9.1 software. The comparison of the means was done by Tukey's test at a probability level of 5 percent.

RESULTS AND DISCUSSION

Grain yield

The results of combined analysis of variance showed that the effect of irrigation, genotype and the interaction effect of irrigation × genotype on grain yield was significantly different (Table 2). In the optimum irrigation, the least grain yield was observed in "Anghane 4" (6310.31 kg ha^{-1}) and "Mashhad" (807.29 kg ha^{-1}), respectively (Table 3). In the moderate stress, the least grain yield was obtained in "Gharaghoz 1" (3778.83 kg ha^{-1}) and "Piranshahr-Andizeh" (493.39 kg ha^{-1}), respectively (Table 4). In the severe stress, maximum and minimum grain yield were obtained in "Salmas-Sadaghian" (2217.95 kg ha^{-1}) and "Mashhad" (490.16 kg ha^{-1}), respectively (Table 5). Hussain *et al*. (2010) showed that cultivar "Kironi" of sunflower presented a good performance under a drought stress compared to hybrid "Hysan-55". Soorninia *et al*. (2012) reported that "B147" and "R46" were suitable parents for producing high yielding and drought tolerant sunflower hybrids. Also, simple correlation coefficients displayed a positive and significant correlation between 1000 grain weight, head diameter, seed number per head and biological yield with grain yield in water treatment conditions (Tables 6, 7 and 8). This finding is similar to those reported by Safavi *et al*. (2011). In the present study, sunflower genotypes exhibited different susceptibilities to drought stress. Based on results, grain yield decreased significantly in the water stress condition. The decrease in grain yield in drought stress was due to a reduction in the physiological activities of plants, cell division, photosynthesis rate, leaf area index and a reduction in stem extension and vegetative growth. Large genetic variations were observed in grain yield between well watered and drought stressed conditions. Several investigators recorded that sunflower cultivars are greatly different in their yield potential (Bakht *et al*., 2010; Elena and Paula, 2010). The results are in line with the findings of Farahvash *et al*. (2011) in sunflower. Elena and Paula (2010), demonstrated that drought stress reduced grain yield and identified "Aldaba" and "Fleuret" as tolerant and "Barolo" and "Flavia" hybrids as sensitive to drought stress in sunflower. Oraki *et al*. (2012) found a large genetic variation for grain yield between well watered and drought stressed conditions in sunflower. Water availability is one of the major agronomical factors that can influence the pro-

Table 3. Means comparison of traits in confectionary sunflower landraces under the optimum irrigation condition.

No	Genotype	Grain yield kg ha^{-1}	Protein percentage (%)	Protein yield kg ha^{-1}	Oil percentage (%)	Oil yield kg ha^{-1}
1	Saghez 1	3241.16^{f-i}	13.42^{e}	446.91^{a-d}	45.17^{a}	1451.55^{a-d}
2	Anghane 4	6310.31^{a}	18.05^{abc}	767.70^{a}	41.29^{a}	1767.02^{a}
3	Urmia-Barouj	3356.1^{e-g}	13.36^{e}	458.08^{a-d}	45.05^{a}	1504.44^{abc}
4	Urmia-Maranghalou	3001.29^{i-n}	17.44^{a-d}	524.57^{a-d}	40.38^{a}	1213.95^{a-f}
5	Marand-Dizaj-Ghalami	3055.14^{i-l}	17.30^{a-e}	528.95^{a-d}	40.06^{a}	1234.51^{a-f}
6	Jabal-Kandi 2	2694.85^{pqr}	17.01^{a-e}	458.68^{a-d}	42.31^{a}	1134.10^{a-f}
7	Salmas-Sadaghian	3177.57^{g-j}	15.10^{a-e}	488.56^{a-d}	42.40^{a}	1350.09^{a-e}
8	Babaghanje 6	3505.71^{cde}	16.11^{a-e}	561.07^{abc}	41.61^{a}	1458.18^{a-d}
9	Miyaneh-Basin	1222.01^{z}	17.08^{a-e}	201.42^{cd}	43.03^{a}	532.49^{def}
10	Bokan	2103.41^{wxy}	15.47^{a-e}	320.90^{bcd}	41.24^{a}	867.33^{a-f}
11	Urmia-Noshinshahr	3012.69^{i-m}	17.55^{a-d}	617.24^{abc}	40.17^{a}	1411.19^{a-e}
12	Karimabad	3727.6^{c}	16.06^{a-e}	595.50^{abc}	41.42^{a}	1551.39^{ab}
13	Vaghaslou-Olya 1	2767.66^{n-q}	13.66^{de}	372.98^{a-d}	43.42^{a}	1200.50^{a-f}
14	Vaghaslou-Olya 3	3500.63^{cde}	18.26^{ab}	639.37^{ab}	41.05^{a}	1444.43^{a-e}
15	Ordoshahi 1	2853.15^{l-p}	18.44^{a}	534.09^{a-d}	41.36^{a}	1171.95^{a-f}
16	Marana-Yamchi-Pesteii	2802.66^{m-q}	18.14^{ab}	512.92^{a-d}	39.22^{a}	1090.64^{a-f}
17	Mazandaran-Tirtash	1674.6^{z}	17.89^{abc}	305.88^{bcd}	39.89^{a}	659.23^{b-f}
18	Sardasht	2356.28^{tuv}	17.11^{a-e}	408.40^{a-d}	38.61^{a}	899.72^{a-f}
19	Marana-Yamchi 4	1783.79^{z}	14.42^{b-e}	260.32^{bcd}	43.09^{a}	770.20^{b-f}
20	Salmas 2	3037.05^{i-m}	15.11^{a-e}	461.81^{a-d}	42.57^{a}	1286.14^{a-f}
21	Vaghaslou-Olya 4	3055.31^{k-o}	14.65^{a-e}	451.63^{a-d}	42.98^{a}	1314.53^{a-e}
22	Salmas-Gharaghash-lagh-Pestei	2691.58^{pqr}	14.09^{cde}	377.47^{a-d}	43.91^{a}	1177.27^{a-f}
23	Lalalou-Torab 2	3418.23^{def}	17.41^{a-d}	593.69^{abc}	38.44^{a}	1312.73^{a-e}
24	Shirabad 2	2591.88^{q-t}	17.14^{a-e}	438.10^{a-d}	44.91^{a}	1165.49^{a-f}
25	Gharaghoz 1	3527.86^{cde}	16.36^{a-e}	577.29^{abc}	43.65^{a}	1537.09^{ab}
26	Vaghaslou-Sofla 1	3635.87^{cd}	15.91^{a-e}	577.87^{abc}	38.48^{a}	1405.59^{a-e}
27	Khanneshan 1	3038.18^{i-m}	17.65^{a-d}	533.13^{a-d}	39.45^{a}	1196.31^{a-f}
28	Heydarlou 1	3103.74^{h-k}	16.26^{a-e}	504.26^{a-d}	39.51^{a}	1230.04^{a-f}
29	Saribaglou 5	3104.84^{h-k}	16.52^{a-e}	512.26^{a-d}	44.98^{a}	1403.78^{a-e}
30	Chongharalou-Yekan 4	2242.85^{vwx}	16.02^{a-e}	358.87^{a-d}	40.82^{a}	916.04^{a-f}
31	Maranghalou 6	2961.75^{j-o}	15.44^{a-e}	449.85^{a-d}	41.49^{a}	1234.92^{a-f}
32	Abajalou 1	3505.04^{cde}	14.88^{a-e}	519.43^{a-d}	39.77^{a}	1397.13^{a-e}
33	Hamadan 1	3513.83^{cde}	14.65^{a-e}	514.41^{a-d}	41.51^{a}	1468.79^{a-d}
34	Saghez 2	2523.74^{r-u}	14.41^{b-e}	363.47^{a-d}	40.01^{a}	1011.40^{a-f}
35	Piranshahr-Sarvkani	1529.61^{z}	18.09^{abc}	278.90^{bcd}	40.28^{a}	624.05^{b-f}
36	Piranshahr-Andizeh	1222.54^{z}	17.60^{a-d}	220.18^{cd}	40.71^{a}	494.03^{ef}
37	Mashhad	807.29^{z}	16.98^{a-e}	140.03^{d}	41.33^{a}	336.34^{f}
38	Shahroud 1	1700.84^{z}	17.07^{a-e}	288.70^{bcd}	41.63^{a}	711.67^{b-f}
39	Hamadan 2	2072.38^{xy}	17.84^{abc}	374.32^{a-d}	41.18^{a}	852.86^{a-f}
40	Shabestar-Kouzeh-Kanan 3	1425.82^{z}	14.61^{a-e}	208.01^{cd}	43.28^{a}	622.25^{b-f}
41	Saghez 4	1458.13^{z}	16.71^{a-e}	246.03^{bcd}	38.40^{a}	557.75^{c-f}
42	Saghez 5	3036.85^{i-m}	16.37^{a-e}	500.57^{a-d}	40.11^{a}	1222.93^{a-f}
43	Saghez 3	2381.37^{tuv}	15.32^{a-e}	365.30^{a-d}	41.65^{a}	988.80^{a-f}
44	Shahroud 2	1942.98^{yz}	15.01^{a-e}	294.06^{bcd}	38.59^{a}	755.37^{b-f}
45	Alibaglou 1	2332.27^{uvw}	15.14^{a-e}	347.62^{bcd}	41.46^{a}	969.01^{a-f}
46	Baneh 2	3241.16^{f-i}	16.39^{a-e}	461.07^{a-d}	41.91^{a}	1180.59^{a-f}
47	Salmas-Gharaghash-lagh-Ghalami	4283.31^{b}	15.89^{a-e}	499.74^{a-d}	42.65^{a}	1337.54^{a-e}
48	Marand-1389-2	3356.1^{efg}	15.35^{a-e}	345.72^{bcd}	40.33^{a}	911.51^{a-f}

No	Genotype	Grain yield kg ha^{-1}	Protein percentage (%)	Protein yield kg ha^{-1}	Oil percentage (%)	Oil yield kg ha^{-1}
49	Salmas-Gharaghash-lagh-Badami	3341.03^{e-h}	15.19^{a-e}	510.44^{a-d}	39.12^{a}	1316.61^{a-e}
50	Shabestar-Kouzeh-Kanan 1	2389.97^{s-v}	16.07^{a-e}	383.22^{a-d}	42.85^{a}	1016.57^{a-f}
51	Sanandaj	2757.08^{o-r}	16.53^{a-e}	454.50^{a-d}	43.87^{a}	1200.62^{a-f}
52	Shabestar-Kouzeh-Kanan 2	2030.62^{xy}	17.33^{a-e}	345.94^{bcd}	40.25^{a}	813.88^{b-f}
53	Baneh 3	2624.02^{p-s}	15.83^{a-e}	414.72^{a-d}	41.39^{a}	1081.00^{a-f}
54	Piranshahr-Balaban	1759.35^{z}	15.82^{a-e}	279.24^{bcd}	42.12^{a}	736.39^{b-f}
55	Baneh 1	3141.86^{g-k}	15.20^{a-e}	478.12^{a-d}	38.52^{a}	1214.77^{a-f}
	Marand-1389-1	3307.52^{e-h}	14.85^{a-e}	491.94^{a-d}	44.01^{a}	1444.58^{a-e}

Means followed by similar letters in each column are non significantly different at the 5% level of probability according to Tukey's test.

duction and quality of sunflower oil (Ali *et al*., 2009). Based on the results, the quality traits of confectionary sunflower were influenced by drought stress. Drought stress caused a reduction in grain yield, oil percentage, protein and oil yield in all studied sunflower landraces. The rate of reduction was different, depending on the genotypes. The studied genotypes presented a great genetic variability to drought stress. Generally, with increasing the stress intensity, grain yield decreased by 25% and 49% in moderate and severe stress compared to the optimum irrigation, respectively.

GMP and STI indices

Based on the STI and grain yield, some of the landraces such as 2, 12, 14, 16, 25, 28, 29, 31, 32, 33, 47, 49 and 56 were drought tolerant with the highest STI and grain yield under mild stress and non-stress conditions (Table 4). In contrast, some of the landraces such as 37 and 38 showed the lowest values for STI and grain yield under mild stress and non-stress conditions. Also, landraces 2, 7 and 12 had the highest STI and grain yield under severe and non-stress conditions, while landraces 36 and 37 showed the lowest value for STI and grain yield under severe and non-stress conditions (Table 5). Khodarahmpour *et al*. (2011) and Khalili *et al*. (2012) reported that STI and GMP indices were more accurate criteria for the selection of heat tolerant and high yielding genotypes. The highest GMP was observed in 2, 12, 14, 25, 26, 28, 31, 32, 33, 49 and 56 landraces under mild stress and non-stress conditions (Table 4). The lowest GMP was observed in landraces 36 and 37 under severe stress and non-stress conditions (Table 4). Under severe and non-stress conditions, the highest GMPs were observed in 2 and 12 landraces, while the lowest GMPs were observed in 36 and 37 landraces (Table 5). Rosielle and Hamblin (1981), demonstrated that the STI and mean productivity (MP) are calculated by the difference in yield and the average yield between stress and non-stress conditions, respectively. Based on results of this study, landraces 2, 7 and 12 were found to be tolerant to drought stress, while landraces 36 and 37 were sensitive to drought stress.

Protein percentage

The effect of irrigation, genotype and the interaction effect of irrigation × genotype on protein percentage was significant (Table 2). The comparison of mean showed that with increasing stress intensity, protein percentage increased so that in moderate and severe stress conditions the protein percentage increased by 5% and 8%, compared to the optimum irrigation respectively (Table 3, 4 and 5). In the optimum irrigation, "Ordoshahi 1" and "Urmia-Barouj" showed the highest and lowest grain protein percentages (18.44 and 13.36%), respectively. In the moderate stress, the maximum and minimum protein percentages were obtained in "Vaghaslou-Olya 3" (19.14%) and "Urmia-Barouj" (14.21%), respectively (Table 4). In the severe stress, the maximum and minimum protein percentages were obtained in "Ordoshahi 1" (19.60%) and "Anghane 4" (14.65%), respectively (Table 5). A negative and significant correlation was observed between protein with oil percentages (Table 6, 7 and 8). There was not a significant correlation between protein percentage with oil

Table 4. Means comparison of traits in confectionary sunflower landraces under moderate drought stress.

No	Genotype	Oil yield Kg ha^{-1}	Oil percentage (%)	Protein yield Kg ha^{-1}	Protein percentage (%)	Grain yield Kg ha-1	STI	Rank	GMP	Rank
1	Saghez 1	809.31^{e-m}	37.52^{abc}	347.76^{a-f}	15.86^{a-d}	2169.72^{h-k}	0.93	19.5	2.65	19.5
2	Anghane 4	646.91^{k-q}	36.17^{abc}	347.94^{a-f}	18.91^{ab}	1807.79^{n-r}	1.51	4	3.38	4
3	Urmia-Barouj	800.45^{e-m}	42.55^{ab}	274.21^{a-f}	14.21^{d}	1883.44^{l-q}	0.84	24	2.51	24.5
4	Urmia-Maranghalou	602.34^{l-q}	37.61^{abc}	301.85^{a-f}	18.36^{abc}	1615.43^{r-u}	0.64	38	2.20	38
5	Marand-Dizaj-Ghalami	718.74^{h-p}	37.69^{abc}	356.44^{a-f}	18.20^{a-d}	1917.77^{l-p}	0.78	27	2.42	27
6	Jabal-Kandi 2	794.41^{f-m}	38.38^{abc}	377.47^{a-f}	17.83^{a-d}	2085.56^{i-l}	0.74	31	2.37	31
7	Salmas-Sadaghian	888.50^{d-l}	40.10^{abc}	357.01^{a-f}	15.99^{a-d}	2211.75^{hij}	0.93	19.5	2.65	19.5
8	Babaghanje 6	804.83^{e-m}	39.05^{abc}	353.17^{a-f}	17.40^{a-d}	2048.18^{j-m}	0.95	17.5	2.68	17.5
9	Miyaneh-Basin	464.22^{pqr}	36.66^{abc}	230.10^{b-f}	18.04^{a-d}	1273.47^{wx}	0.21	54	1.25	54
10	Bokan	373.78^{qr}	38.09^{abc}	158.94^{def}	16.42^{a-d}	973.88^{y}	0.27	51	1.43	51
11	Urmia-NoshinShahr	901.90^{d-l}	36.28^{abc}	460.13^{a-f}	18.51^{abc}	2482.86^{fg}	0.99	15.5	2.73	16
12	Karimabad	1419.72^{ab}	39.25^{abc}	609.89^{ab}	16.92^{a-d}	3611.45^{a}	1.78	1	3.67	1
13	Vaghaslou-Olya 1	551.41^{m-q}	41.21^{abc}	187.57^{c-f}	14.58^{cd}	1328.74^{vwx}	0.49	42	1.92	42
14	Vaghaslou-Olya 3	912.98^{d-k}	34.16^{abc}	516.26^{a-d}	19.14^{a}	2686.43^{ef}	1.25	9	3.07	9
15	Ordoshahi 1	868.96^{d-l}	39.15^{abc}	376.35^{a-f}	17.28^{a-d}	2208.24^{hij}	0.83	25	2.51	24.5
16	Marana-Yamchi-Pesteii	1093.64^{c-f}	37.77^{abc}	536.12^{a-d}	18.72^{ab}	2889.97^{de}	1.07	13.5	2.85	13
17	Mazandaran-Tirtash	706.26^{h-p}	38.25^{abc}	334.45^{a-f}	18.43^{abc}	1832.44^{m-r}	0.41	43	1.75	43
18	Sardasht	621.05^{k-q}	33.43^{bc}	318.38^{a-f}	17.66^{a-d}	1816.67^{m-r}	0.57	41	2.07	41
19	Marana-Yam-Chi 4	537.39^{m-q}	41.28^{abc}	192.58^{b-f}	14.93^{bcd}	1299.26^{vwx}	0.31	48	1.52	48
20	Salmas 2	952.70^{d-j}	40.31^{abc}	370.95^{a-f}	15.68^{a-d}	2367.56^{gh}	0.95	17.5	2.68	17.5
21	Vaghaslou-Olya 4	796.64^{e-m}	41.10^{abc}	293.78 $^{a-f}$	15.32^{a-d}	1927.74^{l-p}	0.75	29.5	2.38	29.5
22	Salmas-Gharaghash-lagh-Pestei	1006.65^{d-h}	42.78^{a}	360.87^{a-f}	15.16^{a-d}	2371.90^{gh}	0.85	23	2.53	23
23	Lalalou-Torab 2	732.67^{h-p}	36.77^{abc}	362.04^{a-f}	18.26^{abc}	2002.13^{j-o}	0.91	21	2.62	21
24	Shirabad 2	733.82^{h-p}	36.43^{abc}	364.67^{a-f}	18.01^{a-d}	2026.19^{j-o}	0.70	33.5	2.29	33.5
25	Gharaghoz 1	1436.98^{a}	38.23^{abc}	651.85^{a}	17.18^{a-d}	3778.83^{a}	1.77	2	3.65	2
26	Vaghaslou-Sofl a 1	1124.58^{bcd}	38.12^{abc}	498.41^{a-f}	16.76^{a-d}	2965.42^{cd}	1.43	5	3.28	5
27	Khanneshan 1	791.29^{g-n}	32.24^{c}	455.09^{a-f}	18.47^{abc}	2467.21^{fg}	0.99	15.5	2.74	15
28	Heydarlou 1	1084.17^{c-g}	37.37^{abc}	495.82^{a-f}	17.05^{a-d}	2908.40^{cde}	1.20	11	3.00	11
29	Saribaglou 5	979.35^{d-i}	34.23^{abc}	496.52^{a-f}	17.57^{a-d}	2853.26^{de}	1.17	12	2.98	12
29	Saribaglou 5	979.35^{d-i}	34.23^{abc}	496.52^{a-f}	17.57^{a-d}	2853.26^{de}	1.17	12	2.98	12
30	Chongharalou-Yekan 4	913.20^{d-k}	39.10^{abc}	387.07^{a-f}	16.62^{a-d}	2344.98^{gh}	0.70	33.5	2.29	33.5
31	Maranghalou 6	1167.01^{a-d}	37.19^{abc}	529.36^{a-d}	16.87^{a-d}	3146.80^{bc}	1.23	10	3.05	10
32	Abajalou 1	1371.18^{abc}	38.13^{abc}	587.27^{abc}	16.30^{a-d}	3596.70^{a}	1.67	3	3.55	3
33	Hamadan 1	1149.52^{a-d}	38.00^{abc}	475.84^{a-f}	15.69^{a-d}	3033.53^{bcd}	1.41	6.5	3.26	7
34	Saghez 2	696.30^{i-p}	38.94^{abc}	278.03^{a-f}	15.53^{a-d}	1799.07^{o-r}	0.60	39.5	2.13	39.5
35	Piranshahr-Sarvkani	602.01^{l-q}	41.65^{ab}	216.93^{b-f}	15.23^{a-d}	1439.76^{t-w}	0.29	50	1.48	50
36	Piranshahr-Andizeh	190.99^{r}	37.55^{abc}	97.81^{ef}	18.77^{ab}	493.39^{z}	0.08	55	0.78	55

No	Genotype	Oil yield kg ha^{-1}	Oil percentage (%)	Prtein yield kg ha^{-1}	Protein percentage (%)	Grain yield kg ha^{-1}	STI	Rank	GMP	Rank
37	Mashhad	185.98^{r}	36.32^{abc}	90.12^{f}	17.76^{a-d}	515.86^{z}	0.06	56	0.65	56
38	Shahroud 1	483.96^{r}	36.82^{abc}	236.72^{a-f}	17.87^{a-d}	1315.93^{vwx}	0.30	49	1.50	49
39	Hamadan 2	493.51^{n-q}	37.90^{abc}	243.60^{a-f}	18.67^{ab}	1285.08^{vwx}	0.35	46.5	1.63	47
40	Shabestar-Kouzeh-Kanan 3	537.93^{m-q}	40.28^{abc}	202.55^{b-f}	15.40^{a-d}	1324.07^{vwx}	0.25	52	1.37	52
41	Saghez 4	392.87^{qr}	34.34^{abc}	206.20^{b-f}	17.45^{a-d}	1177.20^{xy}	0.23	53	1.31	53
42	Saghez 5	632.18^{k-q}	37.97^{abc}	281.33^{a-f}	17.16^{a-d}	1645.39^{q-t}	0.66	37	2.24	37
43	Saghez 3	883.37^{d-l}	40.28^{abc}	348.62^{a-f}	16.06^{a-d}	2183.06^{h-k}	0.69	35.5	2.28	35.5
44	Shahroud 2	544.98^{m-q}	36.37^{abc}	257.84^{a-f}	17.23^{a-d}	1502.04^{s-w}	0.39	44	1.71	44
45	Alibaglou 1	746.24^{h-p}	38.34^{abc}	325.67^{a-f}	16.72^{a-d}	1948.10^{k-p}	0.60	39.5	2.13	39.5
46	Baneh 2	794.95^{f-m}	39.45^{abc}	327.75^{a-f}	16.24^{a-d}	2009.26^{j-o}	0.86	22	2.55	22
47	Salmas-Gharaghash-lagh-Ghalami	792.97^{g-n}	40.14^{abc}	321.39^{a-f}	15.96^{a-d}	1987.24^{j-o}	1.07	13.5	2.85	14
48	Mrand-1389-2	658.12^{j-q}	38.24^{abc}	289.28^{a-f}	16.71^{a-d}	1721.08^{p-s}	0.77	28	2.40	28
49	Salmas-Gharaghash-lagh-Badami	1095.63^{cde}	37.13^{abc}	510.10^{a-e}	17.28^{a-d}	2949.06^{cd}	1.30	8	3.14	8
50	Shabestar-Kouzeh-Kanan 1	900.76^{d-l}	38.97^{abc}	416.55^{a-f}	18.34^{abc}	2305.50^{ghi}	0.73	32	2.35	32
51	Sanandaj	759.19^{h-p}	36.91^{abc}	337.00^{a-f}	16.57^{a-d}	2045.97^{j-n}	0.75	29.5	2.38	29.5
52	Shabestar-Kouzeh-Kanan 2	538.65^{m-q}	38.37^{abc}	231.23^{b-f}	16.51^{a-d}	1403.79^{u-x}	0.38	45	1.69	45
53	Baneh 3	780.07^{h-o}	39.40^{abc}	316.96^{a-f}	15.87^{a-d}	1979.44^{j-o}	0.69	35.5	2.28	35.5
54	Piranshahr-Balaban	601.92^{l-q}	40.12^{abc}	244.60^{a-f}	15.62^{a-d}	1522.93^{s-v}	0.35	46.5	1.64	46
55	Baneh 1	726.01^{h-p}	38.08^{abc}	319.33^{a-f}	16.77^{a-d}	1902.77^{l-p}	0.79	26	2.44	26
56	Mrand-1389-1	1122.22^{bcd}	34.61^{abc}	556.30^{a-d}	17.28^{a-d}	3228.56^{b}	1.41	6.5	3.27	6

Means followed by similar letters in each column are non significantly different at the 5% level of probability according to Tukey's test.

yield and protein yield in the studied water treatment conditions (Table 7). A negative correlation has been reported between grain yield and protein percentages (Lemon, 2007; Subedi *et al*., 2007). Amir *et al*. (2005) observed that peanut (*Arachis hypogaea* L.) plants produced the highest number of kernels and total protein content under an adequate moisture condition. Heidari and Karami (2013), reported a decrease in protein content of sunflower under a moisture stressed condition. The reason for increasing the protein percentage by drought stress is osmo-regulation and water absorption phenomena (Cellier *et al*., 1998). Similar to our results, Esmaeilian *et al*. (2012) found that in sunflower, with increasing drought stress, oil content decreased significantly but protein percentage increased.

Protein yield

On the basis of ANOVA analysis as shown in Table 2, drought stress, genotype and the interaction effect of irrigation × genotype had significant effects on protein yield. In optimum irrigation, the highest and lowest protein yield was recorded in "Anghane 4" (767.70 kg ha^{-1}) and "Mashhad" (140.03 kg ha^{-1}), respectively (Table 3). The comparison of mean showed that with increasing stress intensity, the protein yield decreased by 19% and 44%, in the moderate and severe stresses as compared with the optimum irrigation (Tables 3, 4 and 5). In the moderate stress, the maximum and minimum values for protein yield were obtained in "Gharaghoz 1" (651.85 kg ha^{-1}) and "Mashhad" (90.12 kg ha^{-1}), respectively (Table 4). In the severe stress, "Marand-Dizaj-

Table 5. Means comparison of traits in confectionary sunflower landraces under severe drought stress.

No	Genotype	Oil yield kg ha^{-1}	Oil percentage (%)	Prtein yield kg ha^{-1}	Protein percentage (%)	Grain yield kg ha^{-1}	STI	Rank	GMP	Rank
1	Saghez 1	1272.33^{o-x}	19.35^{ab}	249.13^{a}	33.26^{a-d}	419.16^{e-q}	0.55	26.5	2.03	26.5
2	Anghane 4	1461.19^{k-q}	14.65^{e}	218.75^{a}	34.20^{a-d}	494.72^{a-o}	1.22	1	3.04	1
3	Urmia-Barouj	1575.41^{g-m}	15.30^{cde}	240.83^{a}	41.12^{a}	649.75^{a-l}	0.70	14	2.30	14
4	Urmia-marangh-alou	1170.91^{t-z}	18.84^{a-d}	221.76^{a}	36.70^{a-d}	430.71^{e-q}	0.47	35.5	1.87	36
5	Marand-Dizaj-Ghalami	2065.43^{ab}	18.67^{a-d}	384.28^{a}	33.70^{a-d}	697.93^{a-f}	0.84	4.5	2.51	4.5
6	Jabal-Kandi 2	1415.56^{l-s}	18.22^{a-e}	257.68^{a}	34.13^{a-d}	480.36^{c-o}	0.51	31	1.95	31
7	Salmas-Sadaghian	2217.95^{a}	16.54^{a-e}	368.35^{a}	34.73^{a-d}	771.12^{abc}	0.93	3	2.65	3
8	Babaghanje 6	1002.17^{yz}	17.34^{a-e}	174.51^{a}	35.94^{a-d}	356.78^{k-q}	0.47	35.5	1.87	36
9	Miyaneh-Basin	1462.42^{k-p}	18.23^{a-e}	267.03^{a}	32.90^{a-d}	476.49^{c-o}	0.24	48	1.34	48
10	Bokan	769.14^{z}	16.62^{a-e}	126.96^{a}	36.18^{a-d}	276.12^{n-q}	0.21	50	1.27	50
11	Urmia-Noshinshahr	1783.14^{d-h}	18.81^{abcd}	337.04^{a}	36.09^{a-d}	644.05^{a-l}	0.71	12.5	2.32	12
12	Karimabad	1982.66^{a-d}	17.18^{a-e}	342.71^{a}	37.16^{a-d}	735.13^{a-d}	0.98	2	2.72	2
13	Vaghaslou-Olya 1	1439.29^{l-r}	14.89^{de}	216.51^{a}	38.07^{a-d}	542.77^{a-o}	0.53	28.5	2.00	29
14	Vaghaslou-Olya 3	1453.18^{l-r}	18.81^{a-d}	273.49^{a}	31.61^{bcd}	461.40^{d-q}	0.67	19	2.26	17.5
15	Ordoshahi 1	1611.69^{f-l}	19.60^{a}	317.92^{a}	36.30^{a-d}	583.68^{a-m}	0.61	23	2.14	24.5
16	Marana-Yamchi-Pesteii	1434.58^{l-r}	19.46^{a}	281.72^{a}	34.32^{a-d}	489.45^{a-o}	0.53	28.5	2.01	28
17	Mazandaran-Tirtash	996.16^{yz}	19.16^{abc}	192.53^{a}	37.02^{a-d}	367.97^{h-q}	0.22	49	1.29	49
18	Sardasht	1500.16^{i-o}	18.35^{a-e}	275.50^{a}	31.24^{cd}	466.42^{d-p}	0.47	35.5	1.88	34
19	Marana-Yamchi 4	1177.18^{s-z}	15.66^{a-e}	186.89^{a}	37.62^{a-d}	440.86^{d-q}	0.28	45.5	1.45	45.5
20	Salmas 2	965.81^{z}	16.41^{a-e}	159.85^{a}	36.85^{a-d}	352.14^{l-q}	0.39	42	1.71	42
21	Vaghaslou-Olya 4	1693.70^{e-k}	15.99^{a-e}	272.59^{a}	39.61^{abc}	668.33^{a-h}	0.66	20	2.23	20
22	Salmas-Gharaghashlagh-Pesteii	1901.66^{b-e}	15.38^{b-e}	287.58^{a}	40.46^{abc}	787.91^{a}	0.68	17	2.26	17.5
23	Lalalou-Torab 2	1056.05^{xyz}	18.72^{a-d}	199.11^{a}	35.11^{a-d}	374.81^{g-q}	0.48	33	1.90	33
24	Shirabad 2	1588.41^{g-m}	18.48^{a-e}	293.18^{a}	29.79^{d}	473.62^{c-o}	0.55	26.5	2.03	26.5
25	Gharaghoz 1	1746.63^{d-h}	17.59^{a-e}	305.74^{a}	37.14^{a-d}	658.50^{a-j}	0.82	6	2.48	6
26	Vaghaslou-Sofla 1	1471.15^{j-p}	17.25^{a-e}	251.76^{a}	35.17^{a-d}	523.69^{a-o}	0.71	12.5	2.31	13
27	Khanneshan 1	1703.78^{e-j}	18.96^{abc}	322.54^{a}	32.26^{a-d}	551.63^{a-n}	0.69	15	2.27	15
28	Heydarlou 1	981.17^{z}	17.45^{a-e}	170.23^{a}	35.74^{a-d}	358.20^{j-q}	0.40	40.5	1.75	40
29	Saribaglou 5	2030.66^{abc}	17.85^{a-e}	362.19^{a}	31.74^{bcd}	650.19^{a-l}	0.84	4.5	2.51	4.5
30	Chongharalou-Yekan 4	1567.05^{h-n}	17.36^{a-e}	272.34^{a}	40.61^{ab}	636.43^{a-l}	0.47	35.5	1.87	36
33	Hamadan 1	1453.90^{l-r}	16.05^{a-e}	236.24^{a}	35.95^{a-d}	523.37^{a-o}	0.68	17	2.26	17.5
34	Saghez 2	1807.28^{c-g}	15.75^{a-e}	287.65^{a}	36.82^{a-d}	660.99^{a-i}	0.60	25	2.14	24.5
35	Piranshahr-Sarvkani	860.42^{z}	19.48^{a}	164.80^{a}	34.79^{a-d}	302.78^{m-q}	0.17	52	1.15	52
36	Piranshahr-Andizeh	497.26^{z}	18.95^{abc}	97.21^{a}	35.13^{a-d}	170.13^{pq}	0.08	55	0.78	55
37	Mashhad	490.16^{z}	18.26^{a-e}	90.97^{a}	34.04^{a-d}	163.55^{q}	0.05	56	0.63	56
38	Shahroud 1	1242.51^{p-x}	18.36^{a-e}	228.66^{a}	32.88^{a-d}	403.35^{f-q}	0.28	45.5	1.45	45.5
39	Hamadan 2	1217.73^{r-z}	19.06^{abc}	235.86^{a}	35.44^{a-d}	431.99^{e-q}	0.33	43.5	1.59	43
40	Shabestar-Kouzeh-Kanan 3	689.73^{z}	15.96^{a-e}	105.45^{a}	35.29^{a-d}	245.71^{opq}	0.13	53	0.99	53
41	Saghez 4	525.13^{z}	17.99^{a-e}	94.16^{a}	32.03^{a-d}	163.94^{q}	0.10	54	0.88	54
42	Saghez 5	1801.78^{c-h}	17.66^{a-e}	318.14^{a}	37.09^{a-d}	673.99^{a-g}	0.72	11	2.34	11

No	Genotype	Oil yield kg ha^{-1}	Oil percentage (%)	Prtein yield Kg ha^{-1}	Protein percent-age (%)	Grain yield kg ha^{-1}	STI	Rank	GMP	Rank
43	Saghez 3	2143.35^{a}	16.70^{a-e}	357.20^{a}	36.14^{a-d}	781.94^{ab}	0.68	17	2.26	17.5
44	Shahroud 2	1062.24^{xyz}	16.48^{a-e}	174.48^{a}	33.86^{a-d}	360.78^{i-q}	0.27	47	1.44	47
45	Alibaglou 1	1396.10^{l-t}	17.67^{a-e}	247.60^{a}	36.14^{a-d}	501.64^{a-o}	0.43	38.5	1.80	39
46	Baneh 2	1727.82^{e-i}	17.57^{a-e}	304.88^{a}	38.49^{a-d}	666.58^{a-h}	0.74	10	2.37	10
47	Salmas-Gharaghashlagh-Ghalami	1134.32^{v-z}	16.75^{a-e}	189.59^{a}	38.32^{a-d}	440.06^{d-q}	0.61	23	2.15	22.5
48	Marand-1389-2	1377.34^{l-u}	16.42^{a-e}	227.31^{a}	35.83^{a-d}	496.93^{a-o}	0.61	23	2.15	22.5
49	Salmas-Gharaghashlagh-Badami	1788.36^{d-h}	17.31^{a-e}	309.67^{a}	36.54^{a-d}	656.00^{a-k}	0.79	7	2.44	7
50	Shabestar-Kouzeh-Kanan 1	1370.58^{m-v}	17.71^{a-e}	242.82^{a}	33.65^{a-d}	463.86^{d-q}	0.43	38.5	1.81	38
51	Sanandaj	1335.47^{n-w}	16.72^{a-e}	223.35^{a}	35.27^{a-d}	469.97^{d-p}	0.49	32	1.92	32
52	Shabestar-Kouzeh-Kanan 2	1222.83^{q-y}	17.12^{a-e}	210.74^{a}	34.48^{a-d}	419.13^{e-q}	0.33	43.5	1.58	44
53	Baneh 3	1153.55^{u-z}	16.88^{a-e}	194.90^{a}	35.65^{a-d}	410.22^{f-q}	0.40	40.5	1.74	41
54	Piranshahr-Balaban	828.05^{z}	16.34^{a-e}	135.40^{a}	37.11^{a-d}	309.72^{m-q}	0.19	51	1.21	51
55	Baneh 1	1844.57^{b-f}	16.12^{a-e}	299.71^{a}	31.51^{bcd}	589.96^{a-m}	0.77	9	2.41	9
56	Marand-1389-1	1489.70^{i-o}	17.20^{a-e}	256.55^{a}	32.25^{a-d}	483.36^{b-o}	0.65	21	2.22	21

Means followed by similar letters in each column are non significantly different at the 5% level of probability according to Tukey's test.

Table 6. Matrix of simple correlation coefficient among different traits in confectionary sunflower landraces under optimum irrigation condition.

Characters	Grain yield	Oil percentage	Oil yield	Protein percentage	Protein yield
Grain yield	1				
Oil percentage	0.04^{ns}	1			
Oil yield	0.91**	0.20^{ns}	1		
Protein percentage	-0.07^{ns}	-0.38**	-0.18^{ns}	1	
Protein yield	0.90**	-0.07^{ns}	0.92**	0.16^{ns}	1

**,* and ^{ns}: significant at the 1%, 5% probability levels and non significant, respectively.

Table 7. Matrix of simple correlation coefficient among different traits in confectionary sunflower landraces under moderate drought stress condition.

Characters	Grain yield	Oil percentage	Oil yield	Protein percentage	Protein yield
Grain yield	1				
Oil percentage	-0.11^{ns}	1			
Oil yield	0.98**	0.05^{ns}	1		
Protein percentage	0.02^{ns}	-0.72**	-0.08^{ns}	1	
Protein yield	0.98**	-0.24^{ns}	0.94**	0.20^{ns}	1

**,* and ^{ns}: significant at the 1%, 5% probability levels and non significant, respectively.

Table 8. Matrix of simple correlation coefficient among different traits in confectionary sunflower landraces under severe drought stress condition.

Characters	Grain yield	Oil percentage	Oil yield	Protein percentage	Protein yield
Grain yield	1				
Oil percentage	0.07^{ns}	1			
Oil yield	0.96**	0.30*	1		
Protein percentage	-0.12^{ns}	-0.43**	-0.22^{ns}	1	
Protein yield	0.96**	-0.04^{ns}	0.91**	0.10^{ns}	1

**,* and ^{ns}: significant at the 1%, 5% probability levels and non significant, respectively.

Ghalami" and "Shabestar-Kouzeh-Kanan 3" showed the maximum and minimum values for protein yield, 384.28 kg ha^{-1} and 105.45 kg ha^{-1}, respectively (Table 5). A positive and significant correlation was observed between grain and protein yield (Tables 6, 7 and 8). The reason for decreasing protein yield by drought stress was related to the reduction in grain yield. Researchers have mentioned that the genotype, environmental factors and agronomical managements have important effects on grain protein yield during growth and development of sunflower (Nimbal and Dodamani, 1993). Our findings are in accordance with the finding of Siosamardeh *et al*. (2011) in sunflower which drought stress caused a significant decrease in protein yield. The main reason for the decrease in protein yield by drought stress is related to the reduction in grain yield. For producing high grain yield, we recommend "Anghane 4" for optimum conditions and for severe drought stress conditions "Salmas-Gharagheshlagh-Pestei" and "Salmas-Sadaghian" genotypes are suitable.

Oil percentage

Analysis of variance revealed that the oil percentage is affected significantly by drought stress at 0.01 probability level (Table 2). The oil percentage in sunflower depends on weather conditions, disease attacks during the growing season and the hybrids characteristics (Heidari and Karami, 2013). Khan *et al*. (2000) stated that the oil percentage of sunflower is very sensitive to even mild water stresses. Rauf *et al*. (2012) reported that the oil percentage of sunflower is higher under non-stressed conditions (optimum irrigation) and severe stress causes a decrease in oil percentage. Kassab *et al*. (2012) revealed that the oil percentage of sunflower declined under drought stress. Correlation coefficients showed that there was a negative and significant correlation between oil and protein percentages (Tables 6, 7 and 8). Decreases in oil percentage under drought stress has been reported by other researchers (Afkari Bajehbaj, 2011; Elena and Paula, 2010; Ebrahimian and Bybordi, 2011). Khajae-Pour (2004) found that water stress disrupts grain filling and decreases the synthesis of nutrients and these result in increasing the ratio of hull to kernel and decreasing grain oil content and oil yield. In the present study, drought stress caused a reduction in oil in all studied landraces. This is in agreement with the results of Ali *et al*. (2009).

Oil yield

The results of combined analysis of variance revealed that the effect of irrigation, genotype and the interaction effect of irrigation × genotype on oil yield was significant at probability level of 1% (Table 2). The highest and lowest oil yield values were observed in non-stress and severe drought stress treatments, respectively (Table 3). Ali *et al*. (2009) indicated that by increasing drought stress, the oil percentage and the oil yield of sunflower decreased significantly. Soleimanzadeh *et al*. (2010) investigated the response of sunflower to drought stress and reported that the oil yield decreased significantly by drought stress. They attributed the oil yield decrease under drought stress to the reduction in grain yield. The effect of drought stress on oil yield has been reported by other studies (Tabatabaei *et al*., 2012; Afkari Bajehbaj, 2010; Jabbari *et al*., 2008).

In general, the highest grain, oil and protein yield were obtained from "Anghane 4" genotype under the optimum irrigation condition. However, in moderate and severe stress conditions "Garaghoz 1" and "Salmas-Sadaghian" produced higher grain, oil and protein yield than other landraces. Complementary studies using molecular markers technology are underway in our department to help us identify the genes controlling traits to use in the marker assisted selection.

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