J. Agr. Sci. Tech. (2011) Vol. 13: 327-338

Evaluation of Physiological Indices for Improving Water Deficit Tolerance in Spring Safflower

B. Pasban Eslam[1]*

ABSTRACT

In order to evaluate the physiological indices in relation to the screening of spring safflower genotypes for drought tolerance and productivity, seed and oil yields and yield components were measured for five genotypes including Local Arak, Local Esfahan, Sina, KH_{23-57} and Goldasht. The study was conducted in a loam soil in East Azarbaijan, Iran, during three successive years (2005-2007). Water treatments consisted of non-stressed and water deficit imposed from flowering (80% flowering) to maturity. Several physiological indices including relative water content (RWC), stomatal conductance (K_l), leaf temperature, osmotic adjustment, and specific leaf weight (SLW) were measured. Considering the significant decrease of seeds in capitulum, 1000 seeds weight, harvest index (HI), seed and oil yields due to water deficit, it seems that drought decreased seed and oil yields mainly via declining these components of yield. Since *RWC* and K_l decreased and leaf temperature, osmotic adjustment, and *SLW* were increased significantly by water deficit, therefore these indices could reflect the stress effects during seed filling period. Among *RWC*, K_l, leaf temperature and osmotic adjustment, significant correlations were seen. Also significant positive correlations were found among K_l, *RWC* and *SLW* with seed and oil yield. Screening spring safflower genotypes by the abovementioned characteristics may lead to economically acceptable yields under water deficit condition. Among the genotypes, Goldasht, with 1,412 and 358 kg ha^{-1} seed and oil yields, respectively, had the lowest yield, associated with lower values of R*WC,* K_l and osmotic adjustment. Other genotypes had similar seed and oil yields, while Local Arak had the higher amounts of seed and oil yields, associated with higher values of *RWC,* K_l and osmotic adjustment. It is concluded that Local Esfahan, Sina, KH_{23-57}, and especially Local Arak genotypes, can be used for cultivation in Khosro Shahr and areas with similar climate (cold and semi-arid in Koppen climate classification) under normal and late season drought conditions.

Keywords: Physiological indices, Safflower, Seed and oil yields, Water deficit.

INTRODUCTION

Among the different environmental stresses, drought is the constraint that induces a highly negative effect on crop production. When subjected to this constraint, plants manifest a wide range of behaviors varying from great sensitivity to high tolerance.

Safflower, a strongly tap-rooted annual plant from *Compositae* family, is native to the Middle East. It is resistant to saline condition (Bassil and Kaffka, 2002) and to drought stress (Bassiri *et al*., 1977). Safflower is usually planted in California in the spring to prevent excessive vegetative growth leading to poor seed yield (Kaffka and Kearney, 1998). Total biomass and plant height of safflower genotypes grown in salinized soil (7.2 dS m^{-1}) and drought conditions were proportional to their water use over the range of 400-580 mm (Bassil and Kaffka, 2002).

[1] Research Center for Agriculture and Natural Resources of East Azarbaijan, Tabriz, Islamic Republic of Iran.
* Corresponding author, e-mail: b_pasbaneslam@yahoo.com

The number of capitula per plant and the number of filled seeds per plant were linearly correlated with the number of capitula (Steer and Harrigan, 1986). Saini and Westgate (2000) clearly pointed out that, even though all the reproductive sub-phases are sensible to water deficit in safflower, a water stress during the earliest reproductive stages causes seed and/or flower numbers reduction. Mozaffari and Asadi (2006) studied safflower mutant genotypes under normal and drought conditions and reported positive correlation among capitulum diameter, number of seeds in capitulum, and oil content. Path analysis suggested that in irrigated and drought conditions, the number of seeds in capitulum and 100-seeds weight had the greatest positive direct effects on seed yield. Additional positive impacts were due to the stem diameter, under irrigation, and, under drought,, the number of days to 50% flowering and capitulum diameter. Capitulum weight had the greatest negative direct effect on seed yield under water stress. Effatdoust *et al.* (2004) concluded that, in non-stressed condition, the number of capitula per plant as well as the number of filled and hollow seeds per capitulum is suitable for selection of drought tolerant spring safflower genotypes. For the same purpose and under stress condition, 1000-seeds weight and the number of seeds per capitulum are appropriate. Lovelli *et al.* (2007) state that in safflower, *HI* did not significantly change in five irrigation regimes with a restoration of 100, 75, 50, 25 and 0% of the maximum crop evapotranspiration, but, seed yield declined sharply in severely drought stressed plants. Yau (2006) indicated that later sowing of spring safflower in semi-arid and high-elevation Mediterranean environment resulted in lower seed yield as later flowering does not allow an escape from the terminal drought and heat. Kar *et al*. (2007) found the highest water use efficiency was achieved by safflower with the mean values being 3.04 and 1.23 kg ha^{-1} mm^{-1} with three and one supplemental irrigations, respectively. Also, supplemental irrigation had a significant effect on grain yield so that with one irrigation only 392 kg ha^{-1} grain yield was obtained and yield was enhanced by 48% when two irrigations were applied over one irrigation.

Dordas and Sioulas (2008) reported significant positive correlation between stomatal conductance and assimilation rate, seed yield and oil yield in safflower genotypes that were grown under rainfed condition of Greece. Several physiological characteristics which may contribute to continued growth under water deficit stress have been identified. Osmotic adjustment is considered to be an adaptive characteristic by which an increase in the solute content of cells can lead to maintenance of turgor and turgor related processes at low water potentials (Kumar *et al*., 1984; Singh *et al*., 1990; Kumar and Elson, 1992; Kumar and Singh, 1998). Kumar *et al*. (1984), Singh *et al*. (1985) and Kumar and Singh (1998) have reported close associations between osmotic adjustment and both stomatal conductance and canopy temperature in oilseed *Brassica* species. Singh *et al*. (1985) stated that transpirational cooling (air temperature minus canopy temperature) could effectively be used as a technique to screen *Brassica* genotypes for drought tolerance under receding soil moisture condition. Kumar and Singh (1998) showed significant correlation between seed yield and osmotic adjustment, transpirational cooling, and stomatal conductance in oilseed *Brassica* species. Lehman *et al*. (1993) suggested that, in bentgrass (*Agrostis gigantean* L.), relative water content (RWC) would better predict maintained growth under increasing water deficit than leaf water potential.

The objectives of this study were to evaluate the physiological indices in relation to the screening of spring safflower genotypes for water deficit tolerance and to study seed yield and its components in *Carthamus tinctorius* L. genotypes under drought stress occurring during seed filling stage.

MATERIALS AND METHODS

The experiments were carried out in Agriculture and Natural Resources Research Center of East Azarbaijan, Iran (40° 2″E, 37° 58″N), during three growing seasons (2005-2007). The prevailing weather characteristics during the study are summarized in Table 1. The experiments were conducted as a factorial consisting of two factors based on a randomized complete block design with three replications. Five spring safflower genotypes including Local Arak, Local Esfahan, Sina, $KH_{23\text{-}57}$ and Goldasht were evaluated under non-stressed and water deficit conditions in a loam soil. Water stress was applied on the basis of *MAD* (Mean Allowable Depletion) method (Stegman, 1983). Plants were irrigated at *MAD= 35%* and *MAD= 70%* available soil water depletion in non-stressed and stressed plots, respectively (Table 2). The stress treatment received one irrigation of 25 mm during late flowering (80% flowering) to maturity. In the same period, the non-stressed plots received 75 mm of water in three applications. To avoid precipitation, the stressed plots were covered by polyethylene shelters. There was only one precipitation event for 3 hours in the first year. The plot size was 5 m×2.1 m. Seeds were sown at the bottom of furrows in a 30+60 cm system (one pair of rows in each furrow with 30 cm spacing, and 60 cm spacing between the adjacent rows) on 29 March in all years. Plants were thinned to a spacing of 10 cm within rows, four weeks after sowing. During the growing season, crop management practices, such as pest and weed control and plant nutrition, were carried out as needed. Based on the results of soil testing, nitrogen, phosphorus and potassium fertilizers were applied at the rates of 300,120 and 80 kg ha^{-1}, respectively. Aphid was controlled by Primicarb application during seed filling stage.

The youngest fully-expanded leaves were used for various measurements including leaf temperature, relative water content, stomatal conductance, osmotic adjustment, and specific leaf weight, starting late flowering until leaf senescence. These measurements were done on 10 plants per plot and were repeated four times after the treatments were applied. The average of those measurements were used for data analysis. A hand-held infrared thermometer (Class 2, Testo, Germany) was used to measure leaf temperature (Ray *et al*., 1998). Relative water content (RWC) was obtained by floating the leaf discs (3 discs from each leaf with 20 mm diameter) on distilled water for 4 hours at 5°C under dim light. The turgid weight (TW) was then determined after floating, and the dry weight (DW) after the samples were dried for 24 hours at 80°C. Later, the fresh weight (FW), *TW* and *DW* were used to calculate *RWC* as *RWC= FW-DW/TW-DW* (Jensen *et al*., 1996; Lazcano-Ferrat and Lovatt, 1999). Stomatal conductance (K_l) was determined with an AP_4 prometer (Delta-T Devices, UK). Because both *RWC* and osmotic potential, Ψ_s, are interdependent variables, the regression was fitted with *RWC* as dependent variable using the following equation:

$$\ln RWC = a - b \cdot \ln \Psi_s$$

Where *a* and *b* are intercept and slope of the equation, respectively. Reciprocal of the slope (1/b) is a measure of osmoregulation (Singh *et al*., 1985; Kumar and Singh, 1998). ψ_S was determined by the refrectometry conductivity method (Shimshi and Livne, 1967; Bar-Tsur and Rudich, 1987). To determine specific leaf weight (SLW), the area of the leaves was measured and, then, the leaves were oven dried at 80°C for 48 hours (Wright *et al*., 1996).

Finally, plant and capitulum height, capitulum diameter, seed yield and its components, and seed oil were measured using samples taken from 10 plants in each plot. Seed yield of each plot was determined by harvesting plants in a 6 m^2 frame, excluding the edge plants. Seed oil was determined by NMR (nuclear magnetic resonance) method. Statistical evaluations of

Table 1. Meteorological data for the three growing seasons in Khosro Shahr Station.

Month	Mean minimum air temperature (°C)			Mean maximum air temperature (°C)			Rainfall (mm)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
March	2.4	5.8	3.2	15.5	18.1	12.7	51.3	24.9	53.6
April	9.4	9.5	9.8	21.5	20.9	18.4	73.3	30.4	34.4
May	8.3	16.6	15.1	31.0	30.4	29.4	11.1	0.0	21.5
June	17.2	19.2	18.3	31.3	30.7	30.7	5.7	1.4	0.2
July	19.5	19.4	18.0	33.0	34.6	32.3	4.8	0.0	1.0
August	14.4	15.2	15.8	28.5	31.3	30.2	0.6	0.0	1.8

Table 2. Characteristic of the soil in the experiment field.

Soil depth (cm)	FC^a (%)			WP^b (%)			AWC^c (%)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
0-30	23.0	22.0	21.0	13.5	12.5	13.5	10.0	9.0	9.5
30-65	22.0	20.5	21.0	11.5	12.0	12.5	10.5	10.0	10.0
65-100	15.5	15.0	16.5	8.5	9.5	9.0	9.0	7.0	7.5

[a] Field capacity; [b] Wilting point, [c] Available water capacity.

the data were performed by using MSTAT-C and SPSS software packages.

RESULTS

Yield and Related Characteristics

Drought stress during seed filling stage in the spring safflower genotypes significantly decreased capitulum diameter, number of seeds in capitulum, 1,000 seeds weight, *HI*, seed and oil yields (Tables 3 and 4). Among genotypes significant differences were observed in plant and capitulum height, capitulum diameter, capitula in plant, number of seeds in capitulum, 1,000 seeds weight (TSW), *HI*, seed and oil yields and seed oil percentage (Table 3). The Local Esfahan cultivar had the highest value of plant and capitulum height, while Sina and Goldasht cultivars had the lowest. The highest values of capitulum diameter, seeds in capitulum, and *TSW* belonged to Goldasht, but the lowest amounts of capitula in plant, HI and seed oil belonged to this genotype. Therefore, Goldasht with 1,412 and 358 kg ha^{-1} seed and oil yields, respectively, produced the lowest yield (Table 5). The other genotypes that had similar seed and oil yields were ranked in the same statistical group. Also, these genotypes had higher amounts of capitula in plant, *HI*, and seed oil (Table 5) than Goldasht. Among the studied genotypes, Local Arak produced higher amounts of seed, oil, and *HI* during the three seasons, whereas Goldasht yielded lower (Table 6).

Physiological Indices

Water deficit during seed filling stage significantly decreased *RWC* and K_l, but increased leaf temperature, osmotic adjustment, and *SLW* (Tables 3 and 4). Significant differences were found among spring safflower genotypes in *RWC,* K_l, osmotic adjustment, and *SLW* (Table 3). The lowest values of *RWC*, K_l, and osmotic adjustment belonged to Goldasht, but the highest *SLW* was recorded for Goldasht (Table 5). Higher values of *RWC*, K_l and osmotic adjustment belonged to Local Arak cultivar (Table 5). Interaction effect between genotype and water stress in osmotic adjustment was significant (Table 3). According to Table 7, the lower values of osmotic adjustment belonged to Sina and Goldasht cultivars. Local Arak and KH_{23-57} indicated the highest osmotic adjustment under drought.

Table 8 shows that the correlation between K_l with *SLW*, osmotic adjustment, and leaf temperature were significantly negative. Similar correlations were obtained between *RWC* with osmotic adjustment and leaf temperature, and between *SLW* with *HI.* On the hand, the correlation between osmotic adjustment with leaf temperature, and between K_l with *RWC* and *HI*, were positive and significant. Seed and oil yields were correlated negatively with *SLW* and positively with K_l, *RWC*, and *HI* (Table 8). The correlation between seed yield and leaf temperature were significantly negative. Finally, seed yield was positively correlated to seed oil (Table 8).

DISCUSSION

Since water deficit during the seed filling stage decreased seeds in capitulum, *TSW*, and *HI* it seems that drought decreased seed and oil yields mainly via decreasing the abovementioned components of yield in spring safflower genotypes. One possible explanation for decreasing seeds in capitulum, *TSW*, capitulum diameter, and *HI* could be the limitation of supplying carbohydrates to capitula caused by water stress. Steer and Harrigan (1986) reported that the major components of yield in safflower are the numbers of capitula and filled seeds per plant. According to Saini and Westgate (2000), a water stress during the earlier reproductive stages of safflower causes seed and/or flower number reduction. Mozaffari and Asadi (2006) reported

Table 3. Analysis of variance of the traits measured on spring safflower.

Source	df	Mean squares: Plant height	Capitulum height	Capitulum diameter	Capitula in plant	Seeds in capitulum	1000 seeds weight	Harvest index
Year (Y)	2	352.3**	36.5	31.87**	138.42**	42.2	18.2*	0.020**
Replication (R)	6	238.5**	271.9**	0.85	57.57**	15.3	19.8**	0.002
Stress (S)	1	27.0	14.9	20.74**	0.68	1562.5**	75.8**	0.009**
Y×S	2	63.7	65.0	1.85	33.90	18.4	12.9	0.002
Genotype (G)	4	1478.7**	1023.7**	132.38**	221.63**	368.9**	645.3**	0.016**
Y×G	8	73.7	55.5	1.71	28.97	57.3	9.1	0.006**
S×G	4	40.3	35.4	2.36	2.64	40.4	10.0	0.003
Y×S×G	8	27.5	9.8	2.37	23.48	18.6	1.6	0.001
Error	54	42.0	38.3	1.84	13.90	29.0	4.7	0.001
CV (%)		9.9	12.1	5.1	26.4	12.3	6.1	13.05

*, ** Significant at *P*< 0.05 and *P*< 0.01, respectively.

Table 3 continued

Source	df	Mean squares: Seed yield	Seed oil	Seed oil yield	Leaf temperature	*RWC* [a]	K_l [b]	Osmotic adjustment	*SLW* [c]
Year (Y)	2	2713299**	26.87*	226858**	23.59	0.001	0.002*	0.003	3.41
Replication (R)	6	1142821**	7.54	134956**	57.04**	0.001	0.001	0.079*	6.82
Stress (S)	1	3305866**	0.07	277553**	1652.94**	0.451**	0.769**	79.900**	26.68*
Y× S	2	546169	4.73	36517	87.22**	0.001	0.001	0.030	0.08
Genotype (G)	4	1963273**	127.17**	308141**	11.56	0.007**	0.042**	0.237**	172.26**
Y×G	8	471148	29.66**	60566*	6.07	0.002	0.001	0.045	2.24
S×G	4	357430	2.37	22892	6.15	0.002	0.001	0.250**	1.76
Y×S×G	8	131979	3.85	23227	12.91	0.001	0.001	0.012	1.91
Error	54	260991	5.52	27400	11.69	0.002	0.001	0.025	3.96
CV (%)		25.9	8.1	28.6	17.8	5.6	7.7	7.1	3.8

*, ** Significant at *P*< 0.05 and *P*< 0.01, respectively.
[a] Relative water content; [b] Stomatal conductance, [c] Specific leaf weight.

Table 4. Mean of the traits under non-stressed and stressed conditions.

Stress levels	Capitulum diameter (mm)	Seeds in capitulum	1000 seeds weight (g)	Harvest index	Seed yield (kg ha^{-1})	Seed oil yield (kg ha^{-1})	Leaf temperature (ºC)	*RWC*[a]	K_l[b] (cm s^{-1})	Osmotic adjustment	*SLW*[c]
Non-stressed	27.3	48.0	36.6	0.27	2164	635	14.9	0.76	0.41	1.31	52.1
stressed	26.4	39.6	34.7	0.25	1781	524	23.4	0.62	0.23	3.20	53.2

[a] Relative water content; [b] Stomatal conductance, [c] Specific leaf weight.

Table 5. Mean of the traits measured on spring safflower.

Genotype	Plant height (cm)	Capitulum height (cm)	Capitulum diameter(mm)	Capitula in plant	Seeds in capitulum	1000 seeds weight (g)	Harvest index	Seed yield (kg ha^{-1})	Seed oil (%)
Local Arak	69.1 b	56.6 ab	27.1 b	14.0 b	45.7 a	34.9 b	0.29 a	2284 a	31.8 a
Local Esfahan	76.7 a	59.5 a	25.3 c	16.4 ab	48.4 a	28.5 c	0.25 b	2092 a	29.2 bc
Sina	58.8 c	43.9 c	24.0 d	17.8 a	36.2 b	34.6 b	0.28 a	2072 a	28.9 c
KH_{23-57}	66.7 b	52.3 b	26.8 b	13.7 b	44.1 a	35.2 b	0.27 ab	2000 a	31.2 ab
Goldasht	53.4 c	42.5 c	31.2 a	8.6 c	45.1 a	45.1 a	0.22 c	1412 b	24.5 d
LSD (p=0.01)	5.77	5.51	1.21	3.32	4.83	1.93	0.0281	454.7	2.09

Means for each variable followed by the same letter are not significantly different.

Table 5 continued

Genotypes	Seed oil yield (kg ha^{-1})	*RWC*[a]	*Kl*[b] (cm s^{-1})	Osmotic adjustment	*SLW*[c]
Local Arak	726 a	0.72 a	0.37 a	2.37 a	49.7 d
Local Esfahan	616 a	0.70 ab	0.36 a	2.28 a	52.9 b
Sina	602 a	0.68 ab	0.33 b	2.23 a	50.9 cd
KH_{23-57}	618 a	0.70 ab	0.33 b	2.35 a	52.0 bc
Goldasht	358 b	0.67 b	0.24	2.07 b	57.8 a
LSD (P= 0.01)	147.3	0.0398	0.0281	0.1407	1.77

Means for each variable followed by the same letter are not significantly different.
[a] Relative water content; [b] Stomatal conductance, [c] Specific leaf weight.

Table 6. Mean of the traits measured on spring safflower.

Years	Genotypes	Harvest index	Seed oil (%)	Seed oil yield (kg ha^{-1})
2005	Local Arak	0.28 abcd	30.4 abc	565 bc
	Local Esfahan	0.27 bcdef	30.1 bc	659 abc
	Sina	0.24 def	28.0 bc	458 cd
	$KH_{23\text{-}57}$	0.24 def	34.4 a	564 bc
	Goldasht	0.16 g	23.3 d	199 e
2006	Local Arak	0.32 a	30.9 abc	811 a
	Local Esfahan	0.22 ef	27.4 c	535 bc
	Sina	0.32 ab	30.6 abc	729 ab
	$KH_{23\text{-}57}$	0.30 abc	31.8 ab	670 abc
	Goldasht	0.27 bcde	27.6 c	567 bc
2007	Local Arak	0.27 bcdef	31.1 abc	740 ab
	Local Esfahan	0.27 bcdef	30.0 bc	653 abc
	Sina	0.27 abc	28.2 bc	619 abc
	$KH_{23\text{-}57}$	0.30 cdef	27.4 c	619 abc
	Goldasht	0.26 f	22.6 d	307 de
	LSD	0.0487	3.620	191.6

Means for each variable followed by the same letter are not significantly different.
(*LSD* at the 5% level for seed oil yield and 1% level for other variables).

positive correlation among capitulum diameter, number of seeds per capitulum and oil content in safflower genotypes under drought. Also, Lovelli *et al.* (2007) reported a sharp decline in seed yield for severely drought stressed safflower plants.

Kar *et al*. (2007) observed that, under water deficit condition, supplemental irrigation during reproductive phases, had a significant effect on increasing seed yield. Among the studied genotypes, significant differences were seen in seed and oil yields and their components, and plant capitulum height and diameter. Omidi Tabrizi (2006) evaluated safflower genotypes in three different environmental conditions in Iran and found significant differences among the genotypes in terms of seed and oil yields. Spring safflower genotypes with higher plant and capitulum heights and shorter growing period are suitable mechanized harvesting in Iran. In the present study, Local Esfahan had the highest plant and capitulum height, while Sina and Goldasht genotypes were shorter. The largest capitulum diameter belonged to Goldasht, which also had the highest *TSW*. However, this genotype had the lowest number of capitula per plant, *HI*, and seed oil content. In fact, Goldasht seed and oil yields were, respectively, 1,412 and 358 kg ha^{-1}, the lowest among all of the studied genotypes. Therefore, it seems that Goldasht is not suitable for cultivation in the areas that have a climate similar to the experimental site. The other genotypes had a significantly higher seed and oil yield than Goldasht and were all in one statistical group, although Local Arak had the highest seed oil, *HI*, and

Table 7. Mean of osmotic adjustment measured on spring safflower.

Stress levels	Genotypes	Osmotic adjustment
non-stressed	Local Arak	1.31 e
	Local Esfahan	1.31 e
	Sina	1.27 f
	$KH_{23\text{-}57}$	1.34 e
	Goldasht	1.33 e
stressed	Local Arak	3.39 a
	Local Esfahan	3.24 b
	Sina	3.19 c
	$KH_{23\text{-}57}$	3.36 a
	Goldasht	2.81 d
LSD (P= 0.01)		0.0398

Means for each variable followed by the same letter are not significantly different.

Table 8. Simple correlation coefficients between the traits measured on spring safflower.

Trait	Osmotic adjustment	K_l^a	RWC^b	Leaf temperature	Harvest index	Seed yield	Seed oil	Seed oil yield
SLW^c	0.11	-0.52^{**}	-0.33	0.06	-0.56^{**}	-0.56^{**}	-0.62^{**}	-0.63^{**}
Osmotic adjustment		-0.84^{**}	-0.90^{**}	0.88^{**}	-0.16	-0.31	0.09	-0.24
K_l			0.92^{**}	-0.76^{**}	0.45^{*}	0.64^{**}	0.30	0.62^{**}
RWC				-0.85^{**}	0.34	0.48^{**}	0.19	0.46^{*}
Leaf temperature					-0.24	-0.40^{*}	0.14	-0.30
Harvest index						0.86^{**}	0.51^{**}	0.85^{**}
Seed yield							0.47^{**}	0.97^{**}
Seed oil								0.67^{**}

*, ** Significant at $P< 0.05$ and $P< 0.01$, respectively.

[a] Stomatal conductance; [b] Relative water content, [c] Specific leaf weight.

seed and oil yields in each of the three years of the study. It is concluded that Local Esfahan, Sina, KH_{23-57} and especially Local Arak genotypes, can be used for cultivation in Khosro Shahr and areas with similar climate (cold and semi-arid according to Koppen climate classification) under normal and late season drought conditions.

Since water deficit decreased *RWC* and K_l and increased leaf temperature, osmotic adjustment and *SLW* significantly, it seems that, these indices could reflect the stress effects occurred during seed filling period. Lehman *et al*. (1993) suggested that, *RWC* would better predict maintained growth under increasing water deficit than leaf water potential. Kumar and Singh (1998) showed that seed yield had significant correlation with osmotic adjustment, transpirational cooling, and stomatal conductance in oilseed *Brassica* species. Goldasht indicated lower values of *RWC,* K_l and osmotic adjustment, being associated with lowest seed and oil yields in this genotype. But, the highest *SLW* belonged to Goldasht, which could be related to its thick leaves. Results of a study revealed that soybean genotypes with greater *SLW* provided more photosynthetic proteins per unit ground area (Wells *et al*., 1986). In the present study, Local Arak genotype, with the largest amounts of seed and oil yields, showed higher values of *RWC,* K_l and osmotic adjustment (under drought). Osmotic adjustment is considered to be an adaptive characteristic by which an increase in the solute content of cells can lead to maintenance of turgor and turgor related processes at low water potentials. Finally, the results of our study suggest that *RWC,* K_l, leaf temperature, and osmotic adjustment indices could be used to screen safflower spring genotypes under normal and late season drought conditions.

Also, we found significant correlations among *RWC,* K_l, leaf temperature, and osmotic adjustment and significantly positive correlations between K_l, *SLW*, and *RWC* with seed and oil yields. Accordingly, screening spring safflower genotypes by these last characteristics may give rise to higher yields. Furthermore, *HI* had a significantly positive (0.86 and 0.85 respectively) correlation with seed and oil yields. Thus, *HI* may be a more important character in selection of spring safflower genotypes under normal and drought conditions. Positive correlations between K_l and assimilation rate, seed yield, and oil yield in safflower genotypes have also been reported by Dordas and Sioulas (2008). Several researchers (Kumar and Singh, 1998; Singh *et al*., 1985; and Kumar *et al*., 1984) have reported close associations between osmotic adjustment, stomatal conductance, and canopy temperature in oilseed *Brassica* species.

CONCLUSIONS

Drought during seed filling stage decreased seed yield via reducing seeds in capitulum and 1000-seeds weight. Local Arak, Local Esfahan, Sina and KH_{23-57} genotypes can be used for cultivation in Khosro Shahr and areas with similar climate. Finally, *RWC,* K_l and *SLW* indices can be used to screen safflower spring genotypes for cultivation in areas with late season drought. This study demonstrated the need for further assessment of water deficit tolerance mechanisms in safflower with clear drought cycles and measurements at specific stages of crop growth, using a suitable range of genotypes.

REFERENCES

1. Bar-Tsur, A. and Rudich, J. 1987. Osmotic Adjustment of Cotton to Moderate Potassium-chloride Stress and Subsequent Water Stress during Early Stages of Development. *Agron. J.,* **79:** 166-171.
2. Bassil, E. S. and Kaffka, S. R. 2002. Response of Safflower (*Carthamus tinctorius* L.) to Saline Soils and Irrigation. I. Consumptive Water Use. *Agric. Water Manage.,* **54**: 67-80.
3. Bassiri, A., Khosh-Khui, M. and Rouhani, I. 1977. The Influences of Simulated Moisture

Stress Conditions and Osmotic Substrates on Germination and Growth of Cultivated and Wild Safflowers. *J. Agric. Sci. (Camb.),* **88**: 95-100.
4. Dordas, C. A. and Sioulas, C. 2008. Safflower Yield, Chlorophyll Content, Photosynthesis, and Water Use Efficiency Response to Nitrogen Fertilization under Rainfed Conditions. *Industrial Crops Products,* **27**: 75-85.
5. Effat doust, N., Kazemi, H., Pasban Eslam, B. and Zaeifizadeh, M. 2004. Evaluation of Drought Stress in Different Spring Safflower Genotypes. *Agriculture Congress*, 4-7 October 2004, Malaysia, 72 PP.
6. Jensen, C. R., Mogensen, V. O., Mortensen, G., Fieldsedn, J. K., Milford, G. F. J., Andersen, M. N. and Thage, J. H., 1996. Seed Glucosinolate, Oil and Protein Contents of Field-grown Rape (*Brassica napus* L.) Affected by Soil Drying and Evaporative Demand. *Field Crops Res.,* **47:** 93-105.
7. Kaffka, S. R. and Kearney, T. E. 1998. *Safflower Production in California*. Agriculture and Natural Resources Publication, Davis, UC, 125 PP.
8. Kar, G., Kumar, A. and Martha, M. 2007. Water Use Efficiency and Crop Coefficients of Dry Season Oilseed Crops. *Agric. Water Manage.,* **87**: 73-82.
9. Kumar, A. and Elston, J. 1992. Genotypic Differences in Leaf Water Relations Between *Brassica juncea* and *B. napus. Ann. Bot.*, **70**: 3-9.
10. Kumar, A. and Singh, D. P. 1998. Use of Physiological Indices as a Screening Technique for Drought Tolerance in Oilseed *Brassica* Species. *Ann. Bot.*, **81**: 413-420.
11. Kumar, A., Singh, P., Singh, D. P., Singh, H. and Sharma, H. C. 1984. Differences in Osmoregulation in *Brassica* Species. *Ann. Bot.,* **54**: 537-541.
12. Lazcano-ferrat, I. and Lovatt, C. J. 1999. Relationship between Relative Water Content, Nitrogen Pools and Growth of *Phaseolus vulgaris* L. and *P. acutifolius* A. During Water Deficit. *Crop Sci.,* **39**: 467-475.
13. Lehman, V. G., Engelke, M. C. and White, R. H. 1993. Leaf Water Potential and Relative Water Content Variation in Creeping Bentgrass Clones. *Crop Sci.,* **33**: 1350-1353.
14. Lovelli, S., Perniola, M., Ferrara, A. and Di Tommaso, T. 2007. Yield Response Factor to Water (K_y) and Water Use Efficiency of *Carthamus tinctorius* L. and *Solanum melongena* L.. *Agric. Water Manage.,* **92:** 73-80.
15. Mozafari, K. and Asadi, A. A. 2006. Relationships among Traits Using Correlation, Principal Components and Path Analysis in Safflower Mutants Sown in Irrigated and Drought Stress Condition. *Asian J. Plant Sci.*, **5(6):** 977-983.
16. Omidi Tabrizi, A. H. 2006. Stability and Adaptability Estimates of Some Safflower Cultivars and Lines in Different Environmental Conditions. *J. Agric. Sci. Technol.*, **8**: 141-151.
17. Ray, I. M., Townsend, M. S. and Henning, J. A., 1998. Variation for Yield, Water Use Efficiency, and Canopy Morphology among Nine Alfalfa Germplasm. *Crop Sci.*, **38**: 1386-1390.
18. Saini, H. S. and Westgate, M. E. 2000. Reproductive Development in Grain Crops during Drought. *Adv. Agron.*, **68**: 59-96.
19. Shimshi, D. and Livne, A. 1967. The Estimation of the Osmotic Potential of Plant Sap by Refractometry and Conductometry: a field method. *Ann. Bot.,* **31:** 505-511.
20. Singh, D. P., Chaudhary, B. D., Singh, P., Sharm, H. C. and Karwastra, S. P. S. 1990. *Drought Tolerance in Oilseed Brassica and Chickpea.* Directorate of Research, Haryana Agricultural University, Hisar, India, 27 PP.
21. Singh, D. P., Singh, P., Kumar, A. and Sharma, H. C. 1985. Transpirational Cooling as a Screening Technique for Drought Tolerance in Oilseed Brassicas. *Ann. Bot.*, **56:** 815-820.
22. Steer, B. T. and Harrigan, E. K. S. 1986. Rates of Nitrogen Supply during Different Developmental Stages Affect Yield Components of Safflower (*Carthamus tinctorius* L.). *Field Crops Res.,* **14**: 221-231.
23. Stegman, E. C. 1983. Irrigation Scheduling: Applied Timing Criteria. In: "*Advances in Irrigation*". (Ed.): Hillel, D. Vol. 2, Academic Press, Orlando, Florida, USA, PP. 1-3
24. Wells, R. Ashley, D. A. and Boerma, H. R. 1986. Physiological Comparisons of Two Soybean Cultivars Differing in Canopy Photosynthesis. II. Variation in Specific Leaf Weight, Nitrogen, and Protein Components. *Photosynthesis Res.*, **9**: 295-304.
25. Wright, P. R., Morgan, J. M. and Jessop, R. S. 1996. Comparative Adaptation of Canola (*Brassica napus*) and Indian Mustard (*B. juncea*) To Soil Water Deficit: Plant Water

Relation and Growth. *Field Crops Res.*, **49:** 51-64.

26. Yau, S. K. 2006. Winter versus Spring Sowing of Rain-fed Safflower in a Semi-Arid, High-elevation Mediterranean Environment. *Europ. J. Agronomy,* **26**: 249-256.

ارزیابی شاخص‌های فیزیولوژیک برای بهبود تحمل به کمبود آب درگلرنگ بهاره

ب. پاسبان اسلام

چکیده

به منظور ارزیابی شاخص های فیزیولوژیک مرتبط با گزینش ژنوتیپ های گلرنگ بهاره برای تحمل به خشکی و بررسی محصول دهی آنها، عملکرد دانه، روغن، اجزای عملکرد و نیز چند شاخص فیزیولوژیک شامل مقدار آب نسبی (RWC)، هدایت روزنه‌ای (K_l)، دمای برگ، تنظیم اسمزی و وزن ویژه برگ (SLW) در پنج ژنوتیپ بهاره گلرنگ شامل محلی اراک، محلی اصفهان، سینا، $KH_{۲۳-۵۷}$ و گل‌دشت تحت شرایط عادی و کمبود آب از اواخر گل دهی (۸۰٪ گل دهی) تا رسیدگی دانه اندازه‌گیری شدند. آزمایش‌ها در خاک لومی و در مرکز تحقیقات کشاورزی و منابع طبیعی آذربایجان شرقی (۴۶ درجه و ۲ دقیقه شرقی، ۳۷ درجه و۵۸ دقیقه شمالی) طی سه سال متوالی (۱۳۸۴ تا 13۸۶) اجرا شد. با توجه به کاهش معنی‌دار تعداد دانه در طبق، وزن هزار دانه، شاخص برداشت، عملکرد دانه و روغن در اثر وقوع تنش کمبود آب، به نظر می‌رسد در گلرنگ بهاره تنش خشکی عموماً از طریق کاهش اجزای عملکرد مذکور، باعث افت عملکرد دانه و روغن گردد. نتایج به دست آمده نشان دادند که کمبود آب باعث کاهش معنی‌دار *RWC* و K_l و افزایش معنی‌دار دمای برگ، تنظیم اسمزی و *SLW* گردید. بنابراین چنین استنباط می‌گردد که این شاخص‌ها قادر به بازتاب دادن اثرات خشکی در طول دوره پر شدن دانه در گلرنگ بهاره باشند. همبستگی‌های معنی‌داری بین *RWC*، K_l، دمای برگ و تنظیم اسمزی دیده شد. همچنین بین *RWC*، K_l و *SLW* با عملکرد دانه و روغن همبستگی های مثبت و معنی‌داری به دست آمد. بنابراین به نظر می‌رسد غربال ژنوتیپ‌های بهاره گلرنگ با این شاخص‌ها باعث گزینش ارقام پر محصول‌تر گردد. بین ژنوتیپ‌های مورد مطالعه، گل‌دشت با کسب به ترتیب ۱۴۱۲ و ۳۵۸ کیلوگرم در هکتار عملکرد دانه و روغن، کمترین عملکردها را نشان داد. این در حالی بود که مقادیر پایین‌تری از *RWC*، K_l و تنظیم اسمزی نیز در این ژنوتیپ دیده شد. سایر ژنوتیپ‌ها عملکردهای مشابهی از نظر آماری نشان دادند. ولی محلی اصفهان هماهنگ با کسب مقادیر بالاتر *RWC*، K_l و تنظیم اسمزی، عملکرد دانه و روغن بالاتری نیز داشت. در نهایت چنین استنباط می گردد که ژنوتیپ‌های محلی اصفهان، سینا، $KH_{۲۳-۵۷}$ و به ویژه محلی اراک برای کشت در منطقه خسروشهر و مناطقی با شرایط اقلیمی مشابه (اقلیم سرد و نیمه خشک بر مبنای پهنه‌بندی کوپن) در شرایط عادی و کمبود آب اواخر فصل مناسب می‌باشند.