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EFFECT OF CULTIVAR AND WATER REGIME ON YIELD AND YIELD COMPONENTS IN SAFFLOWER (*Carthamus tinctorius* L.)

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ABSTRACT

Safflower seeds have a high content of oil of good nutritional value. In cereal-based rotations, it can help diversify cropping systems, break disease cycles and control grass weeds. Three winter safflower cultivars (Goldasht, Padideh and K.w.2) were evaluated during two years under five different water regimes in Karaj, Iran. The five water regimes consisted of a control (full irrigated) treatment and four treatments where irrigation was interrupted at bud formation, beginning of flowering, end of flowering, and seed filling. Measurements involved yield and yield components, biomass, plant height, seed oil content, phenological traits and agronomic and irrigation water use efficiency (WUE_a and WUE_i, respectively). No year effect was noted for most measured traits. Highly significant effects of the water regime were found on seed yield, oil yield, days to maturity and the number of capitula per plant. Seed yield and the number of capitula per plant were particularly affected by water shortage at bud formation (36.5 and 37.8%, respectively). The lowest agronomic WUE_a was consequently when irrigation was stopped at beginning of flowering (28.9% less than in full irrigated) and at bud formation (18.3% less than in full irrigated). WUE_i decreased with the quantity of water supplied by irrigation. Water regime did not affect seed oil content. Significant effects of cultivar were found for seed yield, number of capitula per plant, 1000-seed weight, plant height, seed oil content and phenological traits, except days to flowering. Padideh yielded 12.8% more than K.w.2 and 7.6% more than Goldasht. Seed yield was significantly associated with the number of capitula per plant but not with the number of seeds per capitulum and 1000-seed weight. These results demonstrate that bud formation is particularly sensitive to water deficit, and will allow better water management of safflower in semi-arid agriculture.

Keywords: ***Carthamus tinctorius*, oilseed, safflower, water deficit, water use efficiency, yield components**

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is one of the oldest crops, traditionally, grown for its seeds, and used for colouring and flavouring foods and for making red and yellow dyes (Zohary and Hopf, 2000). For the last century, the plant has been cultivated mainly for the oil extracted from its seeds (Corleto et al., 1997). Seed oil content is between 35 and 50% (Camas et al., 2007). Safflower oil is flavourless and colourless, and similar in composition to sunflower oil (Kaffka and Kearney, 1998). The seeds are also a rich source of minerals (Zn, Cu, Mn and Fe), vitamins (thiamine and β-carotene) and tocopherols α, β and γ (Velasco et al., 2005). World production is around 600,000 tons, produced in more than sixty countries worldwide (mainly in India, USA and Mexico) from about 850 000 ha (FAO, 2011).

Safflower is considered as a drought-tolerant crop (Ozturk et al., 2008; Majidi et al., 2011), able to extract water at soil moisture contents that are not available to the majority of crops (Weiss, 2000). However, under drought conditions, the production of considerable amounts of biomass and the extended growing season of this crop may result in depletion of soil water reserves before the crop has matured, leading to low seed yields and harvest index (Wachsmann et al., 2003). Drought stress is reported to cause reduction plant height and decrease seed yield. The amount of water available to the crop is consequently a key factor in determining yield, and the opportunity and modality of irrigation must be determined precisely in local conditions (Ozturk et al., 2008). Conversely, seed oil concentration has been reported to be little affected by drought stress and depend strongly on the genotype (Hang and Evans, 1985).

Iran is attempting to increase local production of oil crops in order to decrease its food oil imports and safflower is considered as a potentially important oil crop for the country (Nabipour et al., 2007). Beneficial for breaking disease cycles and controlling grass weeds, it has been proposed to be cultivated in rotation with wheat (*Triticum aestivum* L. emend. Thell.) (Yazdi-Samadi and Zali, 1979). The planted area just reached 852 ha in 2009

(FAO, 2011). Since it has not been systematically cultivated, information on its adaptation, yield and seed quality is essential. For better cultivation of safflower, a country affected by drought and water shortage, it is particularly important to have a better knowledge of the effects of water shortage at different stages of the growing period on yield components and seed oil content. For these reasons, we undertook experiments comparing irrigation treatments on three local cultivars of safflower.

MATERIALS AND METHODS

Three winter safflower cultivars were evaluated during two years (2005-2006 and 2006-2007) under five different water regimes at the Research Farm of the Seed and Plant Improvement Institute of Karaj, Iran (35° 48 N, 57° 00 E, 1300 m above sea level). Rainfall during the growth cycle was 26% higher in 2006-2007 (350 mm) than in 2005-2006 (277 mm) (Table 1). Rainfall distribution also differed between the two years, with less rain in winter and more in spring in 2006-2007 than in 2005-2006. The soil at the station is a clay loam with a pH of 7.5 and organic matter content of 0.8%. Soil nitrogen content was 0.056% and phosphorus and potassium content were 11.3 and 312 ppm, respectively.

Table 1. Weather statistics during the experimental period at the experimental farm of the Seed and Plant Improvement Institute, Karaj, Iran.

Month	Precipitation (mm)	Average Temperature (C)	Relative humidity (%)
2005			
October	32.3	10.5	55
November	6.6	8.4	46
December	49.8	1.2	89
2006			
January	94.0	4.0	61
February	3.1	9.8	40
March	42.2	17.2	48
April	43.5	19.6	49
May	2.5	24.5	50
June	3.5	27.1	39
July	0.0	27.9	32
August	0.0	25.2	36
September	52.2	20.1	49
October	35.8	11.7	58
November	18.2	2.9	70
December	20.7	-0.3	64
2007			
January	43.0	5.4	60
February	31.5	6.6	62
March	118.7	11.6	59
April	63.1	17.7	51
May	5.3	24.6	41
June	10.0	26.1	47
July	3.8	27.5	35

Two of the cultivars, Goldasht and Padideh, were selected from the population Uromieh (originating from West Azerbaijan, Iran) and the third, K.w.2, was obtained from the cross N133/Rinconada. Planting date in both years was 29 September. In the control treatment (T5), irrigation was applied seven times, namely at emergence, stem elongation, bud formation, beginning of flowering, 50% of flowering, end of flowering and seed filling. Four treatments (T1, T2, T3, and T4) were characterized by termination of irrigation at bud formation, beginning of flowering, end of flowering, and seed filling, respectively. Each irrigation represented a total of 24 mm rainfall equivalent, so that the total quantity of irrigation water was 48 mm in T1, 72 mm in T2, 120 mm in T3, 144 mm in T4, and 168 mm in treatment T5. The total quantity of water received in each treatment (averaged over the two years) was 361.5, 385.5, 433.5, 457.5 and 481.5 in the treatments T1, T2, T3, T4 and T5, respectively.

The experimental design was a split plot in completely randomized block, with 3 replications. Cultivars and treatments were the sub and main plots, respectively. Experimental plots consisted of 4 rows 3 m long and 0.5 m apart. After emergence, seedlings were manually thinned to a uniform density of 20 plants per m^2. Fertilizer comprising 70 kg ha^{-1} of P_2O_5 and 25 kg ha^{-1} of nitrogen as urea was applied prior to sowing and 30 kg ha^{-1} of N was brought as top dressing at the start of stem elongation. Weeds were controlled by hand. Data on yield per plant, yield components and other agronomic traits were recorded on 10 plants randomly selected from the two middle rows. Agronomical measurements included days to bud formation, days to flowering, days to maturity, plant height (from ground level to the tip of main stem at maturity time, in cm), number of capitula, and seed number per capitulum. Total biomass and 1000-seed weight were determined on seed samples dried in an oven at 80°C for 48 h. Seed weight per capita was calculated as the product of seed number per capitulum by 100 seed weight. Oil content of seeds in per cent was determined by Nuclear Magnetic Resonance Spectroscopy, according to IOS (1992), at the National Oilseeds Lab, Seed and Plant Improvement Institute, Karaj, Iran. The seed yield of each plot was determined, and seed and oil yields per hectare were calculated. Agronomic Water Use Efficiency (WUE_a) was calculated as the ratio of seed yield to the total quantity of water available (rainfall and irrigation). Irrigation Water Use Efficiency (WUE_i) was calculated as the ratio of seed yield to the quantity of water supplied by irrigation.

Statistical analysis was performed using PASW 18.0 (SPSS Inc., Chicago, IL, USA). Main and interaction effects of experimental factors were determined from analysis of variance (ANOVA) using the using the same software. Correlation analysis was performed to determine the relationship between the traits and comparisons between means were made using LSD test at $P \leq 0.05$.

RESULTS

No significant year effect was noted, with the exception of days to budding (Table 2). Highly significant effects of the water regime were found on seed yield, biomass, oil yield, days to maturity and the number of

Table 2. The results of analyses of variance (ANOVA), showing year (Y), water treatment (T), cultivar (C) effects and their interactions on yield and yield components, biomass, harvest index, plant height, oil seed content and oil yield, and phenological traits.

Source	Df	Seed yield	Biomass	Harvest index	Number of capitula per plant	Number of seeds per capitulum	1000-seed weight	Plant height	Seed oil content	Oil yield	Days to budding	Days to flowering	Days to maturity
Y	1	8371^{ns}	367617^{ns}	356^{ns}	0.18^{ns}	13.6^{ns}	2.18^{ns}	302^{ns}	0.54^{ns}	277^{ns}	202.5*	11.4^{ns}	62.5^{ns}
T	4	2371299***	3253246*	842^{ns}	46.67***	9.0^{ns}	9.60^{ns}	351*	1.67^{ns}	162261***	67.9^{ns}	63.8*	88.0*
Y * T	4	16056^{ns}	1019442^{ns}	385^{ns}	3.84*	6.5^{ns}	1.84^{ns}	31^{ns}	1.88^{ns}	14.02^{ns}	13.8^{ns}	23.2^{ns}	7.4^{ns}
C	2	342886***	5597981**	104^{ns}	13.64***	46.0*	246.48***	10662***	206.41***	90470***	79.0*	26.1^{ns}	5866.3***
Y * C	2	26570^{ns}	1033265^{ns}	320^{ns}	0.31^{ns}	13.7^{ns}	2.74^{ns}	9^{ns}	2.54^{ns}	4306*	7.2^{ns}	18.8^{ns}	4.4^{ns}
T * C	8	22046*	1385096^{ns}	322^{ns}	4.99**	82.4***	23.33***	428*	7.88***	1795^{ns}	216.3***	151.9***	90.1^{ns}
Y * T * C	8	11961^{ns}	778399^{ns}	346^{ns}	0.77^{ns}	6.7^{ns}	7.04*	100^{ns}	1.46^{ns}	1379^{ns}	17.4^{ns}	23.2^{ns}	14.4^{ns}

*, P <0.05; **, P<0.01; ***, P<0.001; ns, non-significant.

capitula per plant. Highly significant cultivar effects were noted on seed yield, biomass, number of capitula per plant, 1000-seed weight, plant height, seed oil content and phenological traits, except days to flowering. The year x stress interaction was significant only for the number of capitula per plant and the year x cultivar interaction only for oil yield. Highly significant treatment by cultivar interactions were noted for yield, yield components, plant height, seed oil content and days to bud formation and flowering. The interaction between season, treatment and cultivar was not significant, except for 1000-seed weight.

Seed yield, harvest index and oil yield were significantly higher under full irrigation (T5) than under stressed conditions, and decreased with earlier application of drought stress (Table 3). Seed yield and number of capitula per plant were significantly affected when drought stress was applied before flowering. No significant differences were found for these traits when drought stress was applied at bud formation (T1) and at beginning of flowering (T2). Yield was the only trait significantly affected when irrigation was stopped at seed filling (T4), compared to full irrigation. Biomass was less affected than seed yield by water stress. Under T1, the most extreme drought treatment, seed yield and biomass were reduced 36.5% and 8.9%, respectively, from T5 values. The number of capitula per plant also drastically decreased as the drought stress occurred earlier in the growth cycle. In treatment T1, the number of capitula per plant was reduced 37.8% compared to the full irrigation treatment. Conversely, the number of seeds per capitulum and oil content of the seeds were not significantly affected by the treatment and 1000-seed weight was significantly affected only by early stress (T1). Under these conditions, reduction in 1000-seed weight was lower (4.1%) than the reduction in the number of capitula per plant. No clear effect of the water regime was found on phenological traits.

Table 3. Yield and yield components, biomass, harvest index, plant height, seed oil content and oil yield, and phenological traits under the different water regimes and for the three tested cultivars (average of the two years).

Treatment	Seed yield (t ha^{-1})	Biomass (t ha^{-1})	Harvest index	Number of capitula per plant	Number of seeds per capitulum	1000- seed weight (g)	Plant height (cm)	Seed oil content (%)	Oil yield (kg ha^{-1})	Days to budding	Days to flowering	Days to maturity
Water regimes												
T1	1.39^{d}	8.13 ^{c}	17.13^{b}	5.67^{c}	20.06^{a}	27.7^{b}	207^{a}	28.78^{a}	372^{d}	241.1^{a}	252^{b}	302^{ab}
T2	1.36^{d}	8.37^{bc}	16.20^{b}	5.44^{c}	20.89^{a}	28.9^{a}	206^{a}	27.28^{a}	371^{d}	239.3^{ab}	254^{ab}	305^{a}
T3	1.79^{c}	8.88^{ab}	20.24^{b}	7.00^{b}	20.50^{a}	29.4^{a}	205^{a}	26.89^{a}	482^{c}	239.2^{ab}	257^{a}	300^{b}
T4	1.98^{b}	9.17^{a}	21.68^{ab}	8.33^{a}	20.22^{a}	29.6^{a}	196^{b}	27.22^{a}	536^{b}	236.5^{b}	256^{a}	302^{ab}
T5	2.19^{a}	8.92^{ab}	33.26^{a}	9.11^{a}	21.83^{a}	28.9^{ab}	206^{a}	26.56^{a}	580^{a}	237^{b}	253^{b}	306^{a}
Cultivars												
Goldasht	1.72^{b}	8.21^{b}	20.86^{a}	7.53^{a}	19.4^{b}	31.1^{a}	184^{c}	23.9^{b}	412^{c}	236.9^{b}	253.5^{b}	287^{b}
Padideh	1.85^{a}	9.05^{a}	20.41^{a}	7.47^{a}	20.8^{ab}	30.0^{b}	222^{a}	28.2^{a}	522^{a}	238.7^{ab}	255.4^{a}	311^{a}
K.w.2	1.64^{c}	8.82^{a}	23.84^{a}	6.33^{b}	21.9^{a}	25.7^{c}	206^{b}	28.7^{a}	471^{b}	240.1^{a}	254.5^{a}	311^{a}

Mean values in the same column without a common letter are significantly different ($P < 0.05$) according to the Duncan multiple range test.

Table 4. Correlations of seed yield with yield components, biomass, harvest index, plant height, oil seed content and oil yield, and phenological traits for three safflower cultivars in five irrigation treatments (average of the two years).

	Biomass	Harvest index	Number of capitula per plant	Number of seeds per capitulum	1000-seed weight	Plant height	Oil seed content	Oil yield	Days to budding	Days to flowering	Days to maturity
Correlation with seed yield	0.580*	0.941***	0.874***	0.130^{ns}	0.225^{ns}	0.030^{ns}	-0.073^{ns}	0.905***	-0.281^{ns}	0.496***	0.072^{ns}

*P <0.05, ***P<0.001, ns: non-significant.

Seed and oil yield of cv Padideh were significantly higher than those of the other two cultivars (Table 3). Cultivars Padideh and K.w.2 had higher biomass and taller plants than cv Goldasht, but lower 1000-seed weight. Cvs Goldasht and Padideh had more capitula per plant than cv K.w.2. The three cultivars had similar seed weight per capitulum (6.03, 6.24 and 5.61 g, for Goldasht, Padideh and K.w.2, respectively).

Significant correlations were found between seed yield and biomass, harvest index, number of capitula per plant, oil yield and days to flowering (Table 4). A significant correlation was also found between seed yield and the number of capitula per plant for Padideh and K.w.2 (Figure 1).

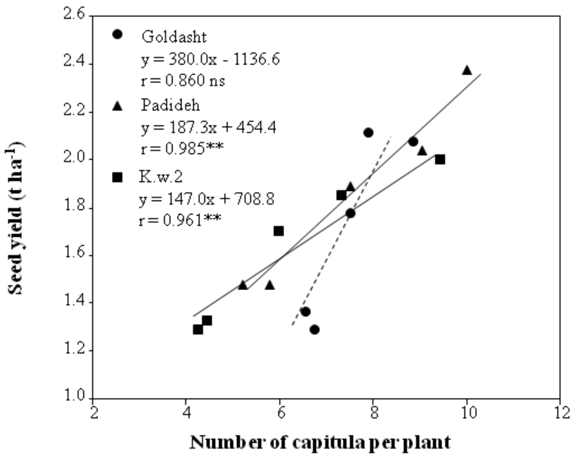

Figure 1. Relationship between number of capitula per plant and seed yield across water treatments in safflower cultivars Goldasht, Padideh and K.w.2 (mean of two years). **, $P < 0.01$

Cv Padideh had the highest yield under most extreme water regimes, while seed yield of cvs Goldasht and K.w.2 were strongly affected by interruption of irrigation at bud formation and beginning of flowering (Figure 2a). The number of capitula per plant was less susceptible to water shortage in cv Goldasht than in cvs Padideh and K.w.2 (Figure. 2b). The reduction of the number of capitula per plant occurring as a consequence of early water shortage was partially compensated by an increase of the number of seeds per capitulum, particularly in the case of K.w.2 (Figure 2c). Under water stress, 1000-seed weight was maintained in cvs Goldasht and K.w.2, but it increased in cv Padideh (Figure 2d).

Agronomic water use efficiency was 0.38, 0.35, 0.41, 0.43 and 0.45 kg kg^{-1} water in the treatments T1, T2, T3, T4 and T5, respectively. The lowest WUE_a was consequently when irrigation was stopped at beginning of flowering (28.9% less than in T5) and at bud formation (18.3% less than in T5). WUE_i was 2.90, 1.89, 1.49, 1.38 and 1.31 kg kg^{-1} in the treatments T1, T2, T3, T4 and T5, respectively. WUE_i decreased with the quantity of water supplied by irrigation and was 55.0% lower in T5 than in T1.

DISCUSSION

Genetic and environmental variation for seed yield and oil content

The success of safflower introduction and development in a given country or region largely depends on seed and oil yield (Bassil and Kaffka, 2002; Malleshappa et al. 2003; Abdolrahmani, 2005). In the present study, seed yield of 1.5-2.0 t ha^{-1} and seed oil content of 24-29% were similar to those obtained previously in Iran (Poordad, 2003) and Turkey (Ozturk et al., 2008) but lower than those reported by some other authors. Previous literature reported seed yield of 1.17 to 3.33 t ha^{-1} (Ozel et al., 2004; Kumbhar et al., 2004; Misra et al., 2005; Ghamarnia and Sepehri, 2010) and seed oil contents of 23.9-40.3% (Ghamarnia and Sepehri (2010) in Iran; and Arslan and Kucuk, 2005, in Turkey). Multi-location traits with other cultivars are needed to determine if the relatively poor performance noted in the present study was due to environmental conditions or to the low potential for seed and oil yield of the tested cultivars. Significant differences were found between cultivars for seed yield and seed oil content, as already reported by Camas et al. (2007).

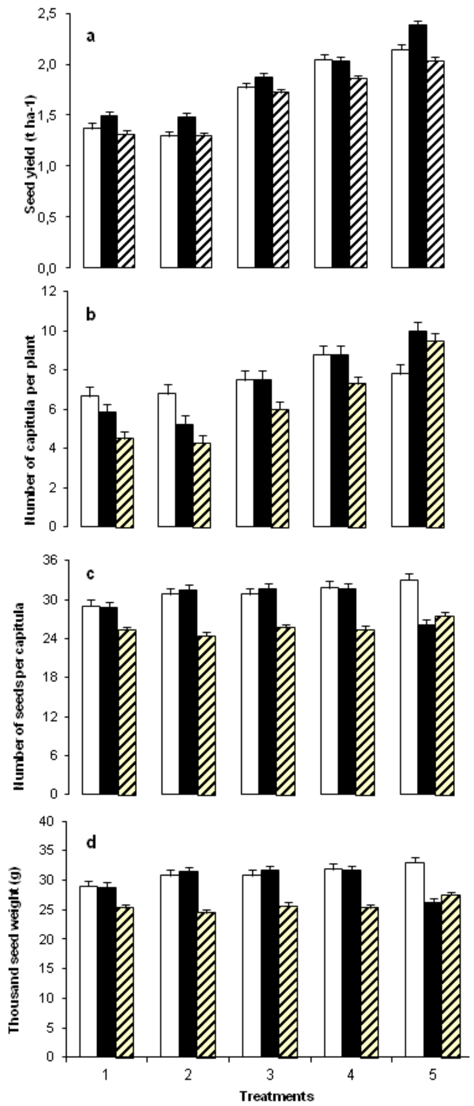

Figure 2. Seed yield, number of capitula, number of seeds per capitulum and thousand-seed weight in safflower cultivars Goldasht (open columns), Padideh (black columns) and K.w.2 (shaded columns) subjected to five irrigation treatments (means of two years).

Ghamarnia and Sepehri (2010) also reported significant differences between cultivars for the number of capitula per plant, number of seeds per capitulum and 1000-seed weight. Safflower has been poorly genetically improved until now for these traits and these results suggest the possibility to realize significant genetic gains.

Effect of water regime on yield, yield components and seed oil content

Seed yield responded strongly to limitation in water availability, as previously reported by Nabipour et al. (2007), Istanbulluoglu (2009) and Ghamarnia and Sepehri (2010). This indicated the importance of irrigation for winter safflower cultivation in the conditions of Karaj (Iran). In the present study, reducing irrigation led to a yield penalty of 10% (T4) to 38% (T2), depending on the growth stage at the time of water shortage. Yield reduction increased as water shortage occurred earlier and quantity of water applied by irrigation was less. Yield and number of capitula were particularly affected when irrigation was stopped before flowering, as already observed by Jabbari et al. (2010). Conversely, stopping irrigation after flowering poorly affected yield components, as previously noted by Sharrifmoghaddasi and Omidi (2010). Nabipour et al. (2007) reported drought stress effects on all yield components. In the conditions of the present study, characterized by water shortage at different stages of the growth cycle, capitulum number was much more affected than 1000-seed weight and seed number, particularly when irrigation was stopped at early stages, as also reported by Movahhedy-Dehnavy et al. (2009). These results confirmed that in safflower, number of capitula depends strongly on water availability (Kaffka and Kearney, 1998). Seed oil content was remarkably constant over the water regimes, confirming previous observations from Hang and Evans (1985). Similar observations were also made in sunflower (Ravishankar et al. 1990).

Different yield responses of safflower cultivars were reported in relation to water shortage timing by Nabipour et al. (2007). In this study, the three cultivars responded similarly to water stress, with Padideh and K.w.2 having the highest and lowest yield, respectively, in most water treatments. Thousand seed weight was the most stable component, showing a large change only in cv Padideh between fully irrigated and partially irrigated treatments. The thousand seed weight is an important plant characteristic since there is a strong positive correlation between seed weight and early vigour (Charjan and Tarar, 1992). Early vigour is an important trait to consider if drought stress occurs mainly at early stages of plants growth cycle.

The ratio of seed yield to the total quantity of water received by the crop (WUE_a) was lower in T2 and T1 than in the other treatments, as a consequence of the drastic effects of water limitation before flowering reported by Jabbari et al. (2010). Conversely, the ratio of seed yield to the quantity of water supplied by irrigation (WUE_i) decreased from T1 to T5, indicating that the additional seed yield obtained by additional irrigation was less that the additional quantity of water supplied. This can be explained by the fact that the quantity of water supplied by each additional irrigation was relatively low, compared to rainfall.

Associations between yield, yield components and seed oil content and yield

Camas et al. (2007) reported significant associations between seed yield and number of capitula per plant, number of seeds per capitulum and 1000-seed weight. In the present study, however, only the number of capitula, the component most affected by water shortage, significantly correlated to seed yield, as previously noted by Beyyavas et al. (2011) in Turkey and Hajghani et al. (2009) in Iran. This component was differently affected by water shortage in the different cultivars tested. The number of capitula was highly stable across water treatments in Goldasht and drastically decreased due to water shortage in the case of K.w.2. The significant association found in the conditions of this study across treatments and cultivars between seed yield and biomass indicates that a higher partition of carbon products to vegetative biomass, as postulated by Wachsmann et al. (2003), does not fully explain the lower seed yield under drought. Moreover, the stronger effect of early water shortage on seed yield and the number of capitula per plant noted in our conditions suggests that water stress, when occurring early during the growth cycle, can affect the initiation and future development of reproductive organs. As seed oil content was stable across environments, oil yield variation was mainly driven by the variation of seed yield.

CONCLUSION

In the present study seed yield, yield components and oil content of seeds were significantly affected by cultivar and water supply, particularly during the early stages of crop development. Among the tested cultivars, Padideh had higher seed and oil yield but lower 1000-seed weight. Goldasht had the highest 1000-seed weight and exhibited a capacity to maintain a high number of capitula across water treatments. These first results re-emphasize the importance of identifying stress-resistant germplasm (Ozturk et al., 2008) and show that it should be possible to improve seed and oil yield, using the high genetic variation in Iranian winter safflower populations (Ghanavati and Knowles, 1977) and combining the respective advantages of cultivars through selection and crossing. Data obtained through this study also emphasized the role of irrigation in safflower performance. By providing a better understanding of the effects of water shortage timing on safflower seed and oil yield, they also might help in a more efficient management of irrigation of the crop. Further studies are needed to identify other management techniques that could enhance seed yield and elucidate the effects of water regime on oil quality and fatty acid composition.

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