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Research Article

Evaluation of late season drought effects on seed and oil yields in spring safflower genotypes

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Abstract: Seed and oil yields, their components, and the relationships among yield and related traits were measured in 5 spring safflower (*Carthamus tinctorius* L.) genotypes, Local Arak, Local Esfahan, Sina, KH_{23-57}, and Goldasht, under nonstressed and water deficit conditions imposed from late flowering (80% flowering) to maturity. The studies were conducted in loam soil at the Research Center for Agriculture and Natural Resources of East Azarbaijan, Iran (46°2′E, 37°58′N) during 3 successive years (2005-2007). According to the significant decrease in the number of seeds per capitulum, 1000-seeds weight, harvest index, and seed and oil yields under water deficit conditions, it seems that drought during the seed filling stage decreases seed and oil yields, mainly through their components. The number of capitula in a plant, a main yield component in safflower, was positively correlated with seed and oil yields. Positive correlations among harvest index, seed oil, and seed and oil yields were obtained. It seems that harvest index may be the most important characteristic for selecting spring safflower genotypes under normal and drought conditions. Results of path analysis revealed that spring safflower genotypes, by having higher seed oil and 1000-seeds weight values, could be cultivated in areas with late season droughts, and spring safflower genotype selection based on plant and capitulum height would be effective. Among the genotypes, Goldasht, with 1412 and 358 kg ha^{-1} seed and oil yields, respectively, showed the lowest values of yield. Other genotypes showed similar seed and oil yields, while Local Arak produced higher seed and oil yields. It was determined that Local Esfahan, Sina, KH_{23-57}, and especially Local Arak could be grown at Khosrowshahr and areas with similar climates (cold and semiarid, according to the Köppen climatic classification) under normal and late season drought conditions.

Key words: Drought stress, path analysis, safflower, seed and oil yields

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 the family Asteraceae, is native to the Middle East. It is resistant to saline conditions (Bassil and Kaffka 2002) and to drought stresses (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

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and plant height in safflower genotypes grown in salinized soil (7.2 dS m^{-1}) and drought conditions were proportional to water use over the range of 400-580 mm (Bassil and Kaffka 2002). It is known that safflower translocates a large percentage (65%-92%) of its preanthesis storage of assimilates to the seed during late season drought stress (Koutroubas et al. 2004).

The number of capitula per plant and the number of filled seeds per plant in safflower were shown to be linearly correlated with each other (Steer and Harrigan 1986). Saini and Westgate (2000) pointed out that all of the reproductive subphases of safflower are sensitive to water deficit. Water stress during early reproductive growth stages reduces seed and/or flower numbers per capitulum. Parameshwarappa and Meghannavar (2001) showed that the number of capitula, seed weight, and seed oil content varies considerably in the safflower population. Mozaffari and Asadi (2006) studied safflower mutant genotypes under normal and drought conditions and reported a positive correlation among capitulum diameter, number of seeds in the capitulum, and seed oil content. Path analysis revealed that the number of seeds in the capitulum, 100-seeds weight, stem diameter under irrigated conditions, days to 50% flowering, and capitulum diameter under drought stress conditions had the greatest positive direct effects, and capitulum weight had the greatest negative direct effects on seed yield. Effatdoust et al. (2004) determined that the number of capitula per plant, number of filled and hollow seeds per capitulum under nonstressed conditions, and 1000-seeds weight and number of seeds per capitulum under stressed conditions were suitable traits for the selection of drought tolerant spring safflower genotypes. Lovelli et al. (2007) showed that the harvest index in safflower did not significantly change in 5 irrigation regimes with a restoration of 100%, 75%, 50%, 25%, and 0% of the maximum crop evapotranspiration, but seed yield declined sharply when drought was severe (Lovelli et al. 2007). It has been reported that the harvest index increased significantly in wheat (Zhang et al. 1998) and maize (Kang et al. 2000) when exposed to water deficit. These authors explained this trend by considering that the early senescence due to water deficit causes a faster grain filling, and in this way a lesser assimilate amount persists in the temporary accumulation organs of the plant as stalks.

Yau (2006) indicated that late sowing of spring safflower in a semiarid and high-elevation Mediterranean environment resulted in lower seed yield as later flowering does not allow an escape from the terminal drought and heat. It was reported that the seed yield of safflower decreased sharply when drought stress was severe (Lovelli et al. 2007). Kar et al. (2007) found that the highest water use efficiency was achieved by safflower with the mean values of 3.04 and 1.23 kg ha^{-1} mm^{-1} when 3 and 1 supplemental irrigations were applied, respectively. Supplemental irrigation also had a significant effect on grain yield. Therefore, while applying 1 irrigation, only 392 kg ha^{-1} of grain yield was obtained, and yield was enhanced by 48% when 2 irrigations were applied over the single irrigation. With 3 irrigations, 1258 kg ha^{-1} of grain yield was obtained, 220% higher than for a single irrigation. Omidi Tabrizi (2006) evaluated safflower genotypes under 3 different environmental conditions, in Karaj, Isfahan, and Darab in Iran, and indicated significant differences among genotypes in seed and oil yield.

The aims of this research were to study the effects of late season drought stress on seed and oil yields and their components, and to evaluate their relationships among spring safflower genotypes.

Materials and methods

The experiments were carried out at the Research Center for Agriculture and Natural Resources of East Azarbaijan, Iran (46°2′E, 37°58′ N) for 3 years (2005-2007). The prevailing weather records during the growing season are summarized in Table 1. The sum of yearly precipitation for the Khosrowshahr station in the long term was 270 mm. The experiments were conducted as a factorial consisting of 2 factors based on a randomized complete block design with 3 replications. Five spring safflower genotypes, Local Arak, Local Esfahan, Sina, KH_{23-57}, and Goldasht, were evaluated under nonstressed and water deficit conditions in a loam soil. Water stress was applied with the mean allowable depletion (MAD) method (Stegman 1983). Plants were irrigated at MAD = 35%

Table 1. Weather records for 3 growing seasons at the Khosrowshahr station during experimental periods.

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	25.5	31.3	30.2	0.6	0.0	1.8

and MAD = 70% available soil water depletion in nonstressed and stressed plots, respectively (Table 2). The stress was imposed from late flowering (80% flowering) to maturity. To avoid the effect of precipitation on stressed plots, polyethylene rain shelters were used during the rainy period (only once for 3 h in the first year). The size of the plots was 5 m × 2.1 m. Seeds were sown at the bottom of furrows in a 30 + 60 cm system (1 pair of rows in each furrow with 30 cm spacing, and 60 cm spacing between 2 paired rows) on 29 March in all years. Plants were thinned to a spacing of 10 cm within rows 4 weeks after sowing. Crop management practices such as pest and weed control and plant nutrition were practiced as needed during the growing season. Finally, plant and capitulum height, capitulum diameter, harvest index, and seed yield and its components, including number of capitula per plant, number of seeds in the capitulum, 1000-seeds weight, and seed oil content, were measured.

Path analysis was used to measure both the direct and indirect effects the yield components may have had on the seed and oil yield of spring safflower genotypes under stressed and nonstressed conditions. Statistical evaluations of the data were performed using MSTAT-C and SPSS.

Results

Yield and related characteristics

Drought stress during the seed filling stage in spring safflower genotypes significantly decreased capitulum diameter, number of seeds in the capitulum, 1000-seeds weight, harvest index, and seed and oil yields (Tables 3 and 4). Among the genotypes, significant differences were observed for plant and capitulum height, capitulum diameter, number of capitula per plant, number of seeds in the capitulum, 1000-seeds weight, harvest index, seed and oil yields, and seed oil percentage (Table 3). Local Esfahan had

Table 2. Characteristics of the soil in the experimental field.

Soil depth (cm)	FC (%)			WP (%)			AWC (%)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
0-30	23.0	22.5	21.0	13.5	12.5	13.5	10.0	9.0	9.5
30-65	22.0	20.5	21.0	11.5	15.0	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

FC = Field capacity, WP = Wilting point, AWC = Available water capacity.

Table 3. Summary analysis of variance of traits measured in spring safflower genotypes.

Source		Mean squares									
	df	Plant height	Capitulum height	Capitulum diameter	Capitula per plant	Seeds in capitulum	1000-seeds weight	Harvest index	Seed yield	Seed oil	Oil yield
Year (Y)	2	352.3**	36.5	31.87**	138.42**	42.2	18.2*	0.020**	2,713,299**	26.87*	226,858**
Replication (R)	6	238.5**	271.9**	0.85	57.57**	15.3	19.8**	0.002	1,142,821**	7.54	134,956**
Stress (S)	1	27.0	14.9	20.74**	0.68	1562.5**	75.8**	0.009**	3,305,866**	0.07	277,553**
Y × S	2	63.7	65.0	1.85	33.90	18.4	12.9	0.002	546,169	4.73	36,517
Genotype (G)	4	1478.7**	1023.7**	132.38**	221.63**	368.9**	645.3**	0.016**	1,963,273**	127.17**	308,141**
Y × G	8	73.7	55.5	1.71	28.97	57.3	9.1	0.006**	471,148	29.66**	60,566*
S × G	4	40.3	35.4	2.36	2.64	40.4	10.0	0.003	357,430	2.37	22,892
Y × S × G	8	27.5	9.8	2.37	23.48	18.6	1.6	0.001	131,979	3.85	23,227
Error	54	42.0	38.3	1.84	13.90	29.0	4.7	0.001	260,991	5.52	27,400
CV (%)		9.9	12.1	5.1	26.4	12.3	6.1	13.05	25.9	8.1	28.6

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

Table 4. Means of traits measured in spring safflower genotypes.

Stress levels	Capitulum diameter (mm)	Seeds in capitulum	1000-seeds weight (g)	Harvest index	Seed yield (kg ha^{-1})	Oil yield (kg ha^{-1})
Nonstressed	27.3	48.0	36.6	0.27	2164	635
Stressed	26.4	39.6	34.7	0.25	1781	524

the highest plant and capitulum height, while Sina and Goldasht had the lowest. All of the cultivars except Sina were shown to have the highest values of capitulum diameter. The highest number of seeds in the capitulum and 1000-seeds weight belonged to Goldasht, while it had the lowest values for capitula per plant, harvest index, and seed oil. Seed and oil yields of this genotype (1412 and 358 kg ha^{-1} seed and oil yields, respectively) were the lowest as compared with the other genotypes under study (Table 5). The differences for seed and oil yields for other genotypes were not statistically significant. These genotypes, in comparison with Goldasht, also had higher values of capitula per plant, harvest indexes, and seed oil percentages (Table 5). Local Arak showed the highest seed oil, harvest index, and seed oil yield values during all 3 years, whereas Goldasht showed the lowest (Table 6).

Correlations among traits

Correlation coefficients among the studied traits are shown in Table 7. Positive correlations were found between plant height and capitulum height, number of capitula per plant, seed oil, and seed and oil yields. The correlation coefficients of plant height with capitulum diameter and 1000-seeds weight were negative. Capitulum height was correlated negatively with 1000-seeds weight and positively with seed oil and oil yield. Capitulum diameter was negatively correlated with the number of capitula per plant, harvest index, seed oil, and oil and seed yields, and positively with 1000-seed weight. The correlation of number of capitula per plant with 1000-seeds weight was negative, and it was positive with harvest index and seed and oil yields. The 1000-seeds weight was negatively correlated with seed oil and oil yield. The correlations of harvest index with seed oil and seed and oil yields were positive.

Table 5. Means of traits measured in spring safflower genotypes.

Genotypes	Plant height (cm)	Capitulum height (cm)	Capitulum diameter (mm)	Capitula per plant	Seeds in in capitulum	1000-seeds Weight (g)	Harvest index	Seed yield (kg ha^{-1})	Seed oil (%)	Oil yield (kg ha^{-1})
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	726 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	616 a
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	602 a
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	618 a
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	358 b
LSD (P = 0.01)	5.77	5.51	1.21	3.32	4.83	1.93	0.0281	454.7	2.09	147.3

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

Table 6. Means of traits measured in spring safflower genotypes.

Years	Genotypes	Harvest index	Seed oil (%)	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$_{23-57}$	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$_{23-57}$	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$_{23-57}$	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 5% level for seed oil and yield; at 1% level for harvest index.

Path analysis

The direct and indirect effects of 5 traits on oil yield under stressed and nonstressed conditions estimated by path coefficients are shown in Table 8. Results of path analysis under 2 conditions were different. All traits in the model indicated positive direct effects on oil yield. Under stressed conditions, seed oil and 1000-seeds weight had the highest and lowest direct effects on oil yield, respectively. Although the 1000-seeds weight under stressed conditions had a positive direct effect on oil yield, its indirect effects through other traits were negative. Under stressed conditions, the direct effects of number of capitula per plant and capitulum height on oil yield were almost the same. Under nonstressed conditions, harvest index and seed oil had the highest and lowest direct effects on oil yield, respectively. Like under stressed

Table 7. Simple correlation coefficients among traits measured in spring safflower genotypes.

Trait	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
(1)	Plant height		0.88**	-0.43*	0.49**	0.27	-0.72**	0.17	0.41*	0.46*	0.49**
(2)	Capitulum height			-0.35	0.23	0.35	-0.70**	0.10	0.48**	0.34	0.43*
(3)	Capitulum diameter				-0.64**	0.30	0.76**	-0.38*	-0.53**	-0.38*	-0.44*
(4)	Capitula per plant					-0.10	-0.55**	0.45*	0.18	0.59**	0.52**
(5)	Seeds in capitulum						0.06	0.08	0.02	0.29	0.26
(6)	1000-seeds weight							-0.23	-0.54**	-0.33	-0.42*
(7)	Harvest index								0.51**	0.86**	0.85**
(8)	Seed oil									0.47**	0.67**
(9)	Seed yield										0.97**
(10)	Oil yield										

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

Table 8. Path analysis showing direct and indirect effects on oil yield measured in spring safflower genotypes under nonstressed and stressed conditions.

Trait	Stress level	Indirect effects				
		Seed oil	Capitula per plant	Capitulum height	Harvest index	1000-seeds weight
Seed oil	Stressed	(0.4380)	0.0259	0.0966	0.1562	-0.1006
	Nonstressed	(0.1690)	0.0880	0.2434	0.1818	-0.0885
Capitula per plant	Stressed	0.0287	(0.3990)	0.0799	0.0888	-0.1033
	Nonstressed	0.0599	(0.2480)	0.2034	0.1418	-0.0648
Capitulum height	Stressed	0.1068	0.0805	(0.3960)	0.0190	-0.1210
	Nonstressed	0.0914	0.1120	(0.4500)	0.1221	-0.0972
Harvest index	Stressed	0.2303	0.1193	0.0253	(0.2970)	-0.0890
	Nonstressed	0.0638	0.0731	0.1143	(0.4810)	-0.0223
1000-seeds weight	Stressed	-0.1791	-0.1675	-0.1948	-0.1075	(0.2460)
	Nonstressed	-0.0637	-0.0684	-0.1863	-0.0456	(0.2350)

Values in parentheses are direct effects.

conditions, all indirect effects of other traits through the 1000-seeds weight were negative. Under nonstressed conditions, seed oil had a low direct effect on oil yield, but through capitulum height and harvest index, a high positive indirect effect on oil yield was shown.

Discussion

Since water deficit during the seed filling stage decreased the number of seeds in the capitulum, the 1000 seeds-weight, the harvest index, and seed and oil yields (Tables 3 and 4), it seems that drought occurring in the late flowering and seed filling stages decreased seed and oil yields, mainly by decreasing the above mentioned components of yield in spring safflower genotypes. A limited supply of carbohydrates to the capitula leads to a reduction in the 1000-seeds weight and harvest index. Steer and Harrigan (1986) reported that the major components of yield in safflower are capitula and filled seed numbers per plant. Saini and Westgate (2000) indicated that water stress during the early reproductive stages of safflower causes seed and/or flower numbers to decrease. Mozaffari and Asadi (2006) reported a positive correlation among capitulum diameter, number of seeds per capitulum, and oil contents in safflower genotypes under drought conditions. It was also reported that the seed yield of safflower declined sharply under severe drought (Lovelli et al. 2007). Abel and Driscoll (1993) showed that the number of capitula per plant and numbers of seeds per capitulum were important traits for producing higher yields in safflower. Kar et al. (2007) observed that supplemental irrigation during reproductive phases under water deficit conditions had a significant effect on increasing seed yield. Among the genotypes, significant differences were seen in seed and oil yields, their components, plant and capitulum height, and capitulum diameter (Table 3). Omidi Tabrizi (2006) evaluated safflower genotypes under 3 different environmental conditions, in Karaj, Isfahan, and Darab in Iran, and indicated that differences among the genotypes in seed and oil yield were significant. The high capitula canopy in spring safflower genotypes leads to improvement in mechanized harvesting. Results also revealed that Local Esfahan had the highest plant and capitulum height and that Sina and Goldasht had the lowest. Goldasht, on the other hand, produced larger capitula and higher 1000-seeds weights, while it produced the lowest number of capitula per plant, harvest index, and seed and oil yields (1412 and 358 kg ha^{-1} seed and oil yields, respectively; Table 5). It seems that Goldasht is not suitable to be grown in Khosrowshahr or other areas with similar climates. Local Arak produced the highest amounts of seed oil, harvest index, and seed and oil yields during all 3 years (Table 6). It was concluded that Local Esfahan, Sina, $KH_{23\text{-}57}$, and especially Local Arak can be used for cultivation in Khosrowshahr and areas with similar climates (cold and semiarid in the Köppen climate classification) under normal and late season drought conditions.

Significant positive correlations were observed between plant height and capitulum height and seed and oil yields (Table 7). Being a taller plant and with taller capitula improves mechanized harvesting in spring safflower genotypes that emerge in the shorter growing period in Iran. Uslu et al. (1998) pointed out that the plant height, number of branches and capitula per plant, and capitulum diameter are always associated with higher yields than the 1000-seeds weight. As Goldasht showed the highest 1000-seeds weight and capitulum diameter and the lowest plant and capitulum heights, number of capitula per plant, harvest index, and seed and oil yields under all conditions, the negative correlations between plant height and capitulum diameter and 1000-seeds weight and between capitulum height and 1000-seeds weight could therefore be seen. Tunçtürk and Çiftçi (2004) indicated a negative and significant relationship between seed yield and percent of protein, but a negative and nonsignificant relationship was found between seed yield and 100-seeds weight. Mozaffari and Asadi (2006) studied mutant genotypes under normal and drought conditions and reported a positive correlation among capitulum diameter, number of seeds in the capitulum, and oil content. The results of one study indicated that the main components of yield in safflower were the number of capitula per plant and the number of seeds in the capitulum, which were linearly correlated with each other (Steer and Harrigan 1986). The number of capitula per plant, as a main yield component in safflower, was positively correlated with seed and oil yields (Table 7). Rudra Naik et al. (2005) reported that the numbers of branches and capitula per plant were the most important effective characteristics for yield and had the highest positive indirect effects on seed yield. Dordas and Sioulas (2008) reported a significantly positive correlation among assimilation rate, seed yield, and oil yield in safflower genotypes that were grown under rainfed conditions in Greece. Among harvest index, seed oil, and seed and oil yield data, positive correlations were obtained (Table 7). It seems that harvest index could be an important characteristic in the selection of spring safflower genotypes under normal and drought conditions. Under stressed conditions, seed oil and 1000-seeds weight had the highest and lowest direct effects on oil yield, respectively, whereas under nonstressed conditions, harvest index and seed oil had the highest and lowest direct effects on oil yield, respectively (Table 8). The indirect effect of the harvest index via the studied characteristics on oil yield under nonstressed conditions was higher in comparison with stressed conditions. An obvious difference was seen between the direct effects of harvest index in 2 irrigation regimes. It was concluded that seed oil and harvest index are suitable criteria in the selecting of safflower genotypes for late season drought and normal conditions, respectively. It seems that the spring safflower genotypes with higher seed oil yields could be suitable for cultivation in areas exposed to late season drought, while harvest index could be a suitable criterion in the selecting of safflower genotypes for normal conditions. Effatdoust et al. (2004) evaluated spring safflower genotypes under drought stress and nonstressed conditions and concluded that, under nonstressed conditions, the number of capitula per plant and numbers of filled and hollow seeds in the capitulum were suitable selection criteria. Under stressed conditions, the 1000-seeds weight and number of seeds in the capitulum were suitable traits for the selection of drought tolerant spring safflower genotypes. Under nonstressed and stressed conditions, capitulum height indicated positive direct and indirect effects on oil yield, respectively, except via the 1000-seeds weight (Table 8), and was correlated positively with plant height (Table 7). Thus, it can be concluded that selection of spring safflower genotypes based on plant and capitulum height would be effective in both environments.

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