Growth and yield of safflower genotypes grown under irrigated and non-irrigated conditions in a highland environment

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ABSTRACT

Producers in highland and semiarid regions have difficulty in increasing diversity in crop rotations due to unfavorable conditions imposed by cool temperatures, inadequate rainfall, and shorter growing periods. In such conditions, safflower appears as a promising alternative because it is cold and drought tolerant. The objective of this study was to determine the responses of the hybrid and open-pollinated safflower genotypes to irrigated and non-irrigated conditions in a highland environment. For this reason, the field research was performed during the years of 2001 and 2002 in eastern Anatolia, Turkey. According to the results of the study, safflower genotypes tested were well adapted to the cool and short-season conditions in this region. The response of seed yield to genotype varied depending on the growing seasons. The non-irrigated plants produced nearly the same seed yield as irrigated ones. Average seed yields of safflower genotypes tested were 914.3 and 928.0 kg/ha in 2001, and 1143.6 and 1139.9 kg/ha in 2002 years for irrigated and non-irrigated experiments, respectively. In general, the genotypes differed in all of the investigated traits. In both irrigated and non-irrigated experiments genotype × year interactions were very significant for all parameters. This research shows that in semiarid and highland environments safflower has a big potential value as an oilseed crop under dryland conditions.

Keywords: safflower; seed yield; adaptation; irrigation; dryland farming; high altitude

Safflower (*Carthamus tinctorius* L.) is a temperate zone plant grown in arid and semiarid regions of world. The crop was initially grown to produce dyes for food and fabric and for medicinal use, but is currently cultivated for edible oil and birdseed (McPherson et al. 2004).

Recently, interest in safflower has been renewed as a result of drought tolerance and the suitability of its oil for nutritional or industrial purposes. Nonetheless, it appears that there has not been an increase in safflower acreage because of a wide variety of problems, mainly due to absence of local markets, unavailability of locally adapted varieties, reluctance of farmers to adopt a new crop, various production challenges, high production costs, and hence it has been of minor importance for a long time. Safflower has been grown on a very limited scale (about 170 ha) in Turkey, with an estimated total production of 200 tones and average productivity of 1176 kg/ha (FAO 2006).

An increasing effort has been made in recent years towards the choice of crops or varieties suitable for dryland conditions. This is crucial to producers in semiarid regions of Turkey including eastern Anatolia, south eastern Anatolia and central Anatolia. Of these regions, eastern Anatolia is typically characterized by long, cold winters, short but warm summers, large diurnal ranges in temperature, frequent strong winds, and variable and unpredictable precipitation. Due to the challenges described here, a limited number of crops are produced in this region. At present, no oilseed crop is grown commercially under the irrigated conditions but sunflower, and no alternative exists for non-irrigated conditions. Hence, for this region it is important to incorporate a new crop into existing cropping system and to increase crop diversity.

Safflower is well adapted to dryland cropping systems, with good drought tolerance due to its deep taproot. The published literature showed that it extracted soil water down to a depth of 4 m (Knowles 1989). However, safflower plant depends on an adequate water supply for optimum growth and development. Several studies have examined the effects of irrigation in safflower. The results indicated that under irrigated conditions it could be very productive (Ibrahim et al. 1991).

In recent years, there has been a proliferation of safflower cultivars, and many excellent genotypes with superior properties are now available. This demonstrates a need for additional research examining the agronomic performances of newly released safflower genotypes in diverse environments. The comparison of yield and other agronomic characteristics of the new genotypes under irrigated and non-irrigated conditions would be useful for agronomist and farmers. On the other hand, safflower is normally reported to grow below 1000 m (Weiss 2000). This fact implies the question whether it can be successfully grown in higher altitude areas.

This study was initiated to evaluate the agronomic performance of commercially available new safflower genotypes under irrigated and non-irrigated conditions in a highland environment in Erzurum, Turkey.

MATERIAL AND METHODS

Two separate field experiments were carried out under irrigated and non-irrigated conditions at Agricultural Experiment and Research Centre of Atatürk University at Erzurum (29°55' N, 41°16' E; 1850 m above sea level) during the seasons 2001 and 2002. The soil of both experiment sites, which is conducted separately at two adjacent fields, was a silty loam (fine, mixed, mesic ustorthents) with pH 7.01 and 1.19% organic matter in 2001 and pH 7.23 and 1.08% organic matter in 2002. Temperature, rainfall, and relative humidity data during the crop-growing period were collected from a weather station that was 1.5 km from the experimental site, and are presented in Table 1. In both experiments, the previous crop on the plots planted in 2001 and 2002 was barley (*Hordeum vulgare* L.). The plot areas were mouldboard ploughed in the fall and cultivated twice in the spring. Four hybrid and eight open-pollinated genotypes were used in this study. The hybrid genotypes were GW 9022, GW 9023, GW 9005, and GW 9003 and the open-pollinated genotypes were Montola 2000, Montola 2001, C 9305, Centennial, Oleic Leed, Dinçer, Yenice, and 5-154-2. The detailed information for these genotypes is given in Table 2.

For all plots both in irrigated and non-irrigated experiment the same management practices, except irrigation and fertilization, were applied. Both experiments were conducted using a randomized complete block design with four replicates each year. Sowings were made on May 1, 2001 and May 2, 2002. The plots were 1.6 m wide and 5 m long and consisted of four rows spaced 0.4 m apart. Plot stands were oversown and hand-thinned approximately at the first four-true leaf stage to 10 cm apart within a row.

Nitrogen and phosphorus were broadcast-applied as ammonium sulphate and triple superphosphate, respectively, and incorporated into the seedbed before sowing. All plots in irrigated and non-irrigated experiments received nitrogen at the rate of kg 120 and 60 kg/ha; phosphorus at the rate of 80 and 40 kg P_2O_5/ha in individual years, respectively. Potassium was not included in fertilization program because soil available K was very high.

Table 1. Monthly and growing season precipitation, temperature, and relative humidity in Erzurum in 2001 and 2002

Months	Precipitation (mm)			Temperature (°C)			Relative humidity (%)		
	2001	2002	normal*	2001	2002	normal*	2001	2002	normal*
May	68.7	73.1	67.5	9.3	9.8	10.3	51.0	55.8	59.4
June	7.3	74.0	31.0	15.4	14.3	15.5	48.1	57.0	52.2
July	36.6	39.1	16.6	20.6	18.3	20.8	46.2	53.0	43.3
August	9.2	54.6	11.7	19.9	16.6	19.4	44.1	53.6	45.2
September	3.8	18.1	33.1	14.3	13.6	14.6	42.0	52.9	48.4
Total or mean	125.6	258.9	159.9	15.9	14.5	16.1	46.3	54.5	49.7

*normal refers to the long-term average (71-year average)

Table 2. The information on safflower genotypes grown under irrigated and non-irrigated conditions, in 2001 and 2002 growing season in Erzurum, eastern Anatolia, Turkey

Genotypes	Pollinated type	Origin	Oil type
GW 9022	hybrid	USA	oleic
GW 9023	hybrid	USA	oleic
GW 9005	hybrid	USA	linoleic
GW 9003	hybrid	USA	linoleic
Montola 2000	open-pollinated	USA	oleic
Montola 2001	open-pollinated	USA	oleic
C 9305	open-pollinated	USA	linoleic
Centennial	open-pollinated	USA	linoleic
Oleic Leed	open-pollinated	USA	oleic
Dinçer	open-pollinated	Turkey	linoleic
Yenice	open-pollinated	Turkey	linoleic
5-154-2	open-pollinated	Turkey	oleic

Weeds were controlled mechanically and by hand-hoeing. In the irrigated experiment, all plots were furrow irrigated regularly to avoid drought stress. The irrigations were scheduled considering the crop water demand, as constrained by water availability. Water was applied uniformly across all plots.

At maturity, data on plant height, head diameter, and seed number per head were taken on twenty randomly selected plants from the central two rows of each plot. The safflower plants were manually harvested at the stage of physiological maturity when they are ready to harvest, i.e. when most of the leaves turn a brown color and very little green remains on the bracts of the latest flowering heads. Seed yields were reported on an oven dry weight basis. Seed oil concentration was determined by the Soxhlet apparatus.

The data were analyzed separately for irrigated and non-irrigated experiments. A combined year analysis of variance was conducted on all data using the GLM procedure of the SAS software (SAS Institute 1990). Homogeneity of error variance was tested before combining data over years. For statistical analyses, cultivar effects were considered fixed and years a random effect. When the *F*-test indicated statistical significance at the $P = 0.05$ level, the protected least significant difference (Protected LSD) was used to separate the means. Planned contrasts were used to compare treatment means. Genotype contrasts were: (i) Turkey vs. USA, (ii) open-pollinated vs. hybrid, and (iii) oleic vs. linoleic.

RESULTS AND DISCUSSION

Air temperature, rainfall, and relative humidity for the experimental site during the study years are presented in Table 1. Long-term average precipitation for the growing season was 159.9 mm. Precipitation was much lower in 2001 than in 2002; precipitation levels for the May through September growing season were 125.6 and 258.9 mm for 2001 and 2002, respectively (Table 1). For the two growing seasons, the total monthly precipitation levels were also highly variable. Precipitation was well distributed throughout the growing season at near-normal levels in 2002. In general, wetter 2002 season provided increased soil moisture levels for longer periods compared with the 2001 growing season. Mean temperatures in the 2001 and 2002 growing seasons were close to the long-term mean. The relative humidity values for the 2002 growing season were higher than in 2001 (Table 1).

In general, cultivars differed in all of the measured traits. Therefore, the genotype main effect was highly significant ($P < 0.05$) (Table 3). Also, there were very significant ($P < 0.01$) genotype × year interactions for all parameters investigated in both irrigated and non-irrigated experiments (Table 3), indicating that genotypes behaved differently in terms of all parameters both in 2001 and 2002.

Yield

In both years safflower genotypes established well under irrigated and non-irrigated conditions. Mean seed yields of safflower genotypes varied depending on the season (Table 3). Safflower genotypes generally produced higher yields in both irrigated and non-irrigated conditions in the 2002 season. The seed yield values for irrigated experiment were 914.3 and 1143.6 kg/ha in 2001 and 2002, and those for non-irrigated experiments 928.0 and 1139.9 kg/ha in 2001 and 2002, respectively. Averaged across two years, the highest seed yield was obtained from the genotype Yenice (1678.1 kg/ha) for irrigated conditions, and from the genotype Oleic Leed (1485.3 kg/ha) for non-irrigated conditions. As seen from Table 3, in irrigated and non-irrigated experiments mean seed yield values showed similar results, with 914.3 (irrigated) and 928.0 (non-irrigated) kg/ha in 2001, and 1143.6 (irrigated) and 1139.9 (non-irrigated) kg/ha in 2002. In both experiments the highest yield (1211 kg/ha for irrigated and 1298 kg/ha for non-irrigated conditions) was obtained from the cultivar Montola 2000 (Table 3).

The yield responses of safflower genotypes varied with irrigated and non-irrigated conditions, which also resulted in significant year × genotype interaction (Table 3). Under irrigated and non-irrigated conditions, the mean seed yields of Turkish genotypes were superior to US genotypes; this difference was however less pronounced under non-irrigated conditions. Furthermore, in irrigated and non-irrigated conditions seed yield of linoleic acid genotypes was lower than that of oleic acid genotypes. The yield values were 1071 versus 986.9 kg/ha for irrigated conditions, and 1061 versus 1007 kg/ha for non-irrigated conditions for oleic and linoleic acid genotypes, respectively.

Yield components

The effect of genotype, year, and year × genotype interaction for plant height were significant ($P < 0.05$) in irrigated and non-irrigated experiments (Table 3). Averaged across years, the highest plant heights were obtained from the genotype Montola 2000, with 117.2 and 83.3 cm for irrigated and non-irrigated conditions, respectively; the genotype 5-154-2 gave the smallest plants with 69.2 and 60.9 cm for irrigated and non-irrigated conditions, respectively. Significant differences among genotypes were observed for plant height both in 2001 and 2002 (Table 3). The heights of the irrigated plants were higher than those of non-irrigated plants.

Head diameter was significantly affected by year in both experiments. Averaged across the years, the values of head diameter of safflower plants were nearly similar for irrigated and non-irrigated experiment. The genotypes showed significant difference in head diameter for both years (Table 3). In both experiments, the highest head diameter was obtained from the genotype Yenice; it had a diameter of 2.35 and 2.16 cm, respectively. The lowest values for head diameter were measured in the hybrid genotypes GW 9022 and GW 9023 (Table 3). The effect of year for irrigated and non-irrigated experiments was significant in both years.

In both irrigated and non-irrigated conditions, seed number per head significantly differed among the genotypes. It ranged from 25.6 (Centennial) to 44.1 (Yenice) for irrigated plants, and from 24.38 (Centennial) to 41.15 (5-154-2) for non-irrigated experiment (Table 3). Likewise, years had a significant effect on this characteristic. Higher seed number per head in both years was obtained from the irrigated experiment.

The 1000 seed weight is an important plant characteristic because a positive correlation exists between seed weight and seedling vigor (Boe 2003). Significant ($P < 0.01$) differences were found between genotypes for 1000 seed weight in both experiments (Table 3). The effect of year on 1000 seed weights was only significant under non-irrigated conditions. Seed weights of genotypes were lower in 2001 than in 2002.

Oil content

With reference to oil content, the results of analysis of variance showed that genotypes significantly differed in both experiments. Under the irrigated conditions, Dinçer had the highest oil content (31.88%), whereas under non-irrigated conditions C 9305 gave the highest oil content (31.45%). Averaged across the growing seasons, the lowest oil content was obtained from the genotype Montola 2000, with 21.55 and 20.76% for irrigated and non-irrigated plants, respectively (Table 3). In both years, similar oil contents were obtained from

Table 3. Mean plant height, head diameter, seed number per head, 1000 seed weight, seed oil content and seed yield of safflower genotypes grown under irrigated and non-irrigated conditions during the 2001 and 2002 growing seasons in Erzurum, Turkey, and the results of analysis of variance

Genotypes		Plant height (cm)		Head diameter (cm)		Seed number per head		1000 seed weights (g)		Seed oil content (%)		Seed yield (kg/ha)	
		irrigated	non-irrigated	irrigated	non-irrigated	irrigated	non-irrigated	irrigated	non-irrigated	irrigated	non-irrigated	irrigated	non-irrigated
GW 9022		79.77	62.88	1.96	1.91	29.33	28.80	35.03	42.14	30.33	27.38	797.0	812.7
GW 9023		80.28	65.23	1.88	2.00	38.07	25.48	35.89	39.66	26.20	27.43	977.9	1007.8
GW 9005		82.33	67.28	2.02	2.07	34.42	30.20	39.43	41.27	28.06	27.42	774.7	1001.7
GW 9003		76.43	68.13	2.15	2.01	30.83	27.53	38.83	41.98	31.00	26.86	930.1	1132.6
Montola 2000		117.20	83.35	2.30	2.15	33.92	37.50	37.04	33.60	21.55	20.76	1211.4	1298.2
Montola 2001		72.63	63.57	2.19	2.10	31.12	28.53	41.33	41.58	29.24	27.74	710.5	596.7
C 9305		75.87	61.27	2.01	1.98	31.90	31.47	38.75	38.60	29.41	31.45	804.3	869.1
Centennial		78.30	64.50	2.06	1.97	25.55	24.38	41.19	36.99	28.62	27.45	818.1	869.7
Oleic Leed		76.88	64.48	2.22	2.06	32.18	29.80	42.65	41.63	29.18	27.59	1549.5	1485.3
Dinçer		82.85	69.87	2.06	2.00	30.60	30.52	38.76	40.18	31.88	30.08	916.3	875.1
Yenice		80.90	70.93	2.35	2.16	44.07	40.73	39.89	43.03	24.08	24.83	1678.1	1294.0
5-154-2		69.20	60.87	2.01	2.03	33.90	41.15	41.40	42.33	29.80	27.24	1179.8	1164.4
$LSD_{0.05}$		2.674	2.329	0.099	0.078	2.087	2.097	2.113	2.088	1.377	1.615	4.275	3.314
2001		77.16	55.91	1.79	1.78	30.14	26.96	39.01	38.90	27.08	26.13	914.3	928.0
2002		84.95	77.81	2.41	2.29	35.84	35.72	39.36	41.60	29.48	28.24	1143.6	1139.9
$LSD_{0.05}$		1.091	0.951	0.041	0.031	0.852	0.856	0.862	0.852	0.562	0.659	1.745	1.353
Analysis of variance													
Sources of variation	*df*												
Year	1	1092.78*	8637.36*	7.31*	4.42*	585.39*	1385.13*	2.25 NS	131.89*	103.96*	79.77*	9466.65*	8086.52*
Genotype	11	871.82*	222.04*	0.12*	0.03*	129.07*	184.52*	32.34*	44.32*	53.04*	40.50*	5936.11*	3758.87*
Repeatability (year)	4	6.08 NS	3.71 NS	0.01 NS	0.01 NS	2.34 NS	1.44 NS	5.27 NS	3.11 NS	1.08 NS	0.77 NS	21.23 NS	5.32 NS
Year × genotype	11	64.49*	45.78*	0.03*	0.04*	11.70*	9.26*	29.70*	9.92*	15.33*	11.51*	290.92*	533.60*
Error	44	5.28	4.01	0.01	0.01	3.22	3.24	3.29	3.22	1.40	1.92	13.50	8.11
Contrasts													
Turkey vs. USA	1	278.12*	3.08 NS	0.04*	0.02 NS	245.54*	900.37*	16.63*	61.28*	2.26 NS	0.91 NS	12592.71*	1431.08*
Open pollinated vs. hybrids	1	65.61*	34.61*	0.34*	0.06*	1.07 NS	104.00*	128.06*	36.95*	13.82*	0.27 NS	9106.56*	736.94*
Oleic vs. linoleic	1	185.92*	1.28 NS	0.01 NS	0.01 NS	0.66 NS	20.69*	6.15 NS	0.63 NS	22.71*	49.42*	1273.18*	521.53*
CV(%)		2.84	2.99	4.07	3.30	5.44	5.76	4.63	4.46	4.19	5.11	3.57	2.75

*significant at $P < 0.01$ or $P < 0.05$; CV = coefficient of variations; NS = not significant the irrigated and non-irrigated experiments. On the other hand, the difference among the years in the oil content was significant in both the irrigated and non-irrigated plants. On average, the wetter year (2002) gave higher oil content. Although it was not significant, seed oil content increased with irrigation. Hybrid genotypes had more oil content than open pollinated cultivars in both experiments, as would be expected. There were no significant differences between US and Turkish genotypes in terms of oil content in both experiments. In addition, the oil contents of genotypes with linoleic acid were superior to those of genotypes with oleic acid under irrigated and non-irrigated conditions.

Seed yield plays an important role in determining the economics of safflower. Seed yields of the genotypes significantly varied depending on the experimental years. The fact that safflower produced higher yields in both irrigated and non-irrigated in the 2002 season was probably the result of the greater amount of rainfall in the second year. Overall, seed yield of safflower in the present study was lower than that reported by Pourdad and Beg (2005). The low yields in the present study as well as in our previous study could be due to environmental conditions, i.e. short growing season, cool temperatures, and high altitude. In this location, the only attempt to grow safflower was made by Esendal (1973) using 20 old genotypes under irrigated conditions. Our data concur with the earlier study which demonstrated that mean yields were 1256 and 816 kg/ha for the 1969 and 1970 crop seasons, respectively.

The results of the present study also give evidence that genotype differences for seed yield existed in both irrigated and non-irrigated experiments. Cultivar differences for seed yield in safflower had been reported previously (Esendal 1973). On the other hand, mean seed yields showed almost similar results for irrigated and non-irrigated safflower plants. The absence of expected response to irrigation appears to be related to very poor conditions. Indeed, it was unexpected and the most striking result of this study. In safflower there is a general agreement that seed yield is increased by irrigation (Ibrahim et al. 1991). However, the results of some research seem to support our finding that there has been no marked response to irrigation in safflower. For example, the work of Haby et al. (1982) demonstrated that at only one of three sites seed yield of safflower was increased by irrigation.

Similar yields obtained for irrigated and non-irrigated experiments can be associated with the water uptake ability of safflower roots up to the depth of 4 m in the soil profile under dry conditions, probably since the shortage of soil water had a stimulating effect on the growth of plant roots (Knowles 1989). On the other hand, Bassil and Kaffka (2002) reported that seed yield of safflower was not correlated with water use.

Climatic conditions varied greatly during the course of this study, particularly for the amount and distribution of precipitation during the growing seasons. In the first study year, the plants received less precipitation at rosette stage compared to the second year, but we think that this situation does not undesirably influence seed yield. Weiss (2000) also reports that safflower is tolerant to moisture shortage at the rosette stage, and dry conditions at this time do not appear to have a major effect on subsequent growth and yield. The author also points out that safflower can be substantially independent of rainfall, since it is capable to obtain moisture from levels not available to majority of crops, and that if sufficient pre-planting soil moisture is available, i.e. approximately two-thirds of total water requirements, the remainder can occur as rain with no major depressing effect on yield.

Another interesting result of the present study is that under both irrigated and non-irrigated conditions open pollinated genotypes yielded more than hybrids. The difference between open pollinated and hybrid genotypes was more pronounced in safflower grown under irrigated conditions. In general, there is a common belief among producers that seed yield of hybrids are superior to those of open pollinated cultivars. This is in contrast to what was observed in the earlier work (Gonzalez and Schneiter 1994). However, the results of Wachsmann et al. (2003), who found that some open-pollinated cultivars could produce more seed yield than hybrid cultivars depending on location, is in agreement with our findings. The low yields may be associated with the smaller head diameters of hybrids such as GW 9022 and GW 9023.

Results of the analysis of variance showed that plant height was significantly affected by genotype and year (Table 3). Plant height is a trait under genetic control, but its manifestation depends on prevailing environmental factors. Our results concur with the results of others (Pascual-Villalobos and Alburquerque 1996, Koutroubas et al. 2004) documenting that safflower genotypes differed in plant height. Overall, lower plant heights in the current study were probably caused by high altitude. This agrees with the study of Kofidis et al. (2003), who found that oregano plants grown at high altitude were shorter than those grown at low altitude. Plant shortening at high altitude is presumably associated with shorter growing period and reduced temperatures, as well as with nutrient and water limitations. According to Kofidis et al. (2003), the reduced height of upland plants further reflects an adaptive strategy to avoid the damaging mechanical effect of strong winds at high elevation. As expected, the irrigated plants were higher than non-irrigated ones. This tendency was also observed in the study of Bassil and Kaffka (2002). However, in 2001, a drier year, we observed greater plant height response to irrigation. A wet year produced taller plants than a dry year, suggesting that precipitation plays a key role in plant growth.

In both irrigated and non-irrigated experiments, head diameter significantly varied with years and genotypes. In the second growing season, greater heads were obtained because of higher total rainfall amount and better monthly distribution of rainfall. As observed in seed yield, head diameters of safflower plants were nearly similar under irrigated and non-irrigated conditions (Table 3). Literature sources (Esendal 1973, Ashri et al. 1976) confirm that head diameter varies with different genotypes. As seen in Table 3, the head diameter values were low, probably because of the adverse environmental factors at the experimental site such as semiarid climate, cool temperatures and shorter growth period.

Year and genotype had a significant effect on seed number per head for both irrigated and non-irrigated experiment. Compared to the non-irrigated conditions, the lack of response to irrigation can be explained partly by the fact that its deep-rooting characteristic allows plants to draw moisture and nutrients from a considerable volume of soil.

The effect of genotype for 1000 seed weight was significant in both experiments (Table 3). In previous studies, it has been established that 1000 seed weight of safflower is genotype-dependent (Alizadeh and Carapetian 2006). On the other hand, the effect of year was significant only in non-irrigated conditions. This result was expected, due to higher rainfall during the second year. Seed weights of safflower genotypes were lower in 2001 than in 2002. However, this difference was not significant under irrigated conditions.

The oil contents of safflower genotypes grown under both irrigated and non-irrigated conditions significantly differed. In the present study, we obtained higher oil contents compared to the previous study (Esendal 1973) conducted in this region. Clearly, this shows that newly released genotypes were superior to old genotypes. Previous investigations showed that differences in seed oil content were inherent among cultivars (Pascual-Villalobos and Alburquerque 1996). Nonetheless, it was frequently observed that the same cultivar, when grown in different years or in different environments in the same year, varies significantly in oil content. In both years, irrigated and non-irrigated plants had similar oil contents. Also, the higher oil content was obtained from the wetter year. Compared to the non-irrigated conditions, seed oil content increased with irrigation, but this increase was insignificant. Our results are generally in agreement with that of Alessi et al. (1977), who reported that water stress decreased oil concentration. In contrast, Hang and Evans (1985) observed that oil concentration of safflower did not respond to increased irrigation rates. Generally, lower oil contents in our study were probably associated also with the high altitude. This conclusion is supported by the fact that oil content decreased with increasing altitude as reported by Weiss (2000).

As previously stated, eastern Anatolia has limited crop diversity due to high altitude and adverse climatic conditions. Currently, wheat is the predominant crop grown under dry conditions in the region, and there is no alternative oilseed suitable for the region growers to be included in rotation with small grain cereals. This study confirmed the importance of safflower as a dryland crop and its potential for diversifying wheat-based cropping systems in semiarid regions of Turkey. This research also provided useful information on the suitability of safflower to highland environment and on the comparison of genotypic responses in irrigated and non-irrigated conditions. In our case, safflower showed generally high adaptability to eastern Anatolia conditions. With high seed yields, Yenice, Oleic Leed and Montola 2000 were found to be promising genotypes for both irrigated and non-irrigated conditions. The results of the present study suggest that safflower should be considered a strong alternative within oilseeds crops particularly for non-irrigated areas, since it is a deep-rooted annual crop that might be useful for improving the overall water and N use efficiencies of cropping systems, helping to minimize nitrate leaching to groundwater and diversifying cropping systems.

Acknowledgements

The authors sincerely thank Dr. Burhan Arslan, Dr. Enver Esendal, and Dr. Özden Öztürk for providing safflower genotypes, and the staff of Agricultural Research and Extension Center, Atatürk University, for their help in conducting this study.

REFERENCES

Alessi J., Power J.F., Zimmerman D.C. (1977): Sunflower yield and water use as influenced by planting date, population, and row spacing. Agron. J., *69*: 465–469.

Alizadeh K., Carapetian J. (2006): Genetic variation in a safflower germplasm grown in rainfed cold drylands. J. Agron., *5*: 50–52.

Ashri A., Urie A.L., Zimmer D.E. (1976): Evaluation of the germ plasm collection of safflower, *Carthamus tinctorius* L. VII. Variability of capitulum width and outer involucral bracts' dimensions. Euphytica, *25*: 225–229.

Bassil E.S., 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.

Boe A. (2003): Genetic and environmental effects on seed weight and seed yield in switchgrass. Crop Sci., *43*: 63–67.

Esendal E. (1973): A Research on the Phenological and Morphological Traits, and Yields and Seed Properties of Some Domestic and Foreign (*Carthamus tinctorius* L.) Cultivars Grown under Erzurum Ecological Conditions. Atatürk University Publishing, Erzurum. (In Turkish)

FAO (2006): Food and Agriculture Organization of the United Nations – FAOSTAT. Available at: http://www.apps.fao.org

Gonzalez J.L., Schneiter A.A. (1994): Response of hybrid and open-pollinated safflower to plant population. Agron. J., *86*: 1070–1073.

Haby V.A., Black A.L., Bergman J.W., Larso R.A. (1982): Nitrogen fertilizer requirements of irrigated safflower in the Northern Great Plains. Agron. J., *74*: 331–335.

Hang A.N., Evans D.W. (1985): Deficit sprinkler irrigation of sunflower and safflower. Agron. J., *77*: 588–592.

Ibrahim A.F., Sharaan A.N., El-Wakil A.W. (1991): Water requirements of safflower entries in middle Egypt. J. Agron. Crop Sci., *3*: 70–175.

Knowles P.F. (1989): Safflower. In: Robbelen G., Downey R.K., Ashri A. (eds.): Oil Crops of the World. McGraw-Hill, New York: 363–374.

Kofidis G., Bosabalidis A.M., Moustakas M. (2003): Contemporary seasonal and altitudinal variations of leaf structural features in oregano (*Origanum vulgare* L.). Ann. Bot., *92*: 635–645.

Koutroubas S.D., Papakosta D.K., Doitsinis A. (2004): Cultivar and seasonal effects on the contribution of pre-anthesis assimilates to safflower yield. Field Crops Res., *2*: 263–274.

McPherson M.A., Allen G.G., Keith A., Topinka C., Linda M.H. (2004): Theoretical hybridization potential of transgenic safflower (*Carthamus tinctorius* L.) with weedy relatives in the New World. Can. J. Plant Sci., *84*: 923–934.

Pascual-Villalobos M.J., Alburquerque N. (1996): Genetic variation of a safflower germplasm collection grown as a winter crop in Southern Spain. Euphytica, *3*: 327–332.

Pourdad S.S., Beg A. (2005): Status of safflower research and development in rainfed condition of Iran. In: VIth Inter. Safflower Conf., Istanbul, Turkey.

SAS Institute (1990): SAS/STAT User's Guide, Version 6.4. SAS Institute, Cary.

Wachsmann N., Knights S., Norton R., Jochinke D. (2003): The performance of imported safflower (*Carthamus tinctorius* L.) hybrids in south-eastern Australia. In: Australian Agronomy Conf., Geelong, Australia. Available at: http://www.regional.org.au/au/asa

Weiss E.A. (2000): Oilseed Crops. Blackwell Science, Oxford.

Received on August 8, 2008

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