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ORIGINAL PAPER

Effect of Irrigation Regimes on Oil Content and Composition of Safflower (*Carthamus tinctorius* L.) Cultivars

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Abstract Safflower oil contains a large amount of unsaturated fatty acids, however, the composition of the oil may be affected by drought stress. This experiment determined the effect of three irrigation regimes (60, 75 and 90% soil moisture depletions of available water) on oil composition of safflower cultivars (Kuseh, PI and IL111). Amounts of oil and oil composition of the seeds were determined by gas chromatography (GC). The oil contents of IL111, PI and Kuseh cultivars were 30.73, 27.63 and 25.25%, respectively. The oil contents, palmitic, stearic, oleic and linoleic acid contents were reduced by about 13, 63, 60, 14 and 10% by drought, respectively. The stearic acid contents of PI, IL111 and Kuseh were reduced by 72, 61 and 37% and palmitic acid contents of the same cultivars were reduced by drought by 65, 53 and 51%, respectively. Whereas, the linoleic acid contents of Kuseh, PI and IL111 were reduced by only 10, 8 and 5% and oleic acid contents of the same cultivars were reduced by only 14, 13 and 14% under the drought stress, respectively. The results showed that although drought stress reduced the amount of oil and oil composition of safflower cultivars, the decrease was due to a dramatic reduction in saturated fatty acids contents. Thus, proper irrigation regimes may enhance safflower oil quality.

Keywords Irrigation regimes · Oil composition · Safflower

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Introduction

In dry land cropping systems, water is the most important limiting factor for crop production. One of the keys to irrigated crop production is correct crop choice to achieve a stable quality under drought stress. Safflower (*Carthamus tinctorius* L.) is an important oilseed crop particularly in arid and semi-arid regions of the world due to its cold, drought and salinity tolerance [1]. Safflower oil contains the unsaturated fatty acids linoleic acid and oleic acid and the saturated fatty acids stearic acid and palmitic acid [2]. Oleic acid has good frying characteristics, namely, stability and a bland flavor [3], while linoleic acid reduces the cholesterol level in the blood [4, 5].

Ordinary safflower oil contains about 2–3% stearic acid, 16–20% oleic acid, 6–8% palmitic acid and 71–75% linoleic acid [6]. Whereas, high oleic safflower oil contains over 85% oleic acid and high linoleic safflower contains 87–89% linoleic acid [7, 8]. Though the genotype is the most important factor that determines the oil content and fatty acid composition, environmental factors such as drought also affect the oil content and fatty acid composition of the seed [7]. Drought was reported to increase oleic acid content of high oleic sunflower hybrids, but decrease it in ordinary hybrids [9]. An increase in linoleic and a decrease in oleic acid contents of sunflower under water stress have been reported by others [10]. It has also been reported that drought had little effect on fatty acid composition of soybean seed [11] and a reduction in linoleic acid and oleic content of canola under drought stress was observed [12]. Other reports indicate that mid-seasonal drought had no effect, while late season drought significantly reduced total oil and linoleic acid contents and increased the stearic and oleic acid contents of groundnut seed (Peanut) [13].

Though amount of oil and the fatty acid composition of aerial parts of safflower under drought stress were studied [14], there is little or no information on the effect of drought stress on oil content and fatty acids composition of safflower seeds. The fatty acid composition of oil determines its commercial value and drought could have a dramatic and dynamic effect on both quality and quantity of oil that is extractable by seed processors. It is important to determine the effect of drought on oil content and fatty acid composition of safflower seeds. Therefore, this investigation was conducted to determine the effect of three irrigation regimes on oil and oil composition of three safflower cultivars in the field.

Materials and Methods

The field experimental design was a split-plot (3 × 3) arranged in a completely randomized design with three replications conducted at Lavark (Latitude 32°32′ N, Longitude 51°23′ E, Altitude 1,630 m above sea level with a long-term rainfall of 140 mm) in 2007 and 2008. The main plot consisted of three irrigation regimes (60 (I_{60}), 75 (I_{75}) and 90 (I_{90}) percentage soil moisture depletions of available water) and the sub-plot was three cultivars (Kuseh, PI and IL111). The irrigation was based on evaporation from class A pan and 70 (I_{60}), 105 (I_{75}) and 140 (I_{90}) mm evaporation were considered as normal (no stress), mild stress and severe stress, respectively (Table 1). Available water (AW) was calculated as AW = FC–PWP. The soil was classified as an Aridisol type with a clay loam texture. The soil bulk density (ρb), mass soil moisture at field capacity (θ_{FC}), mass soil moisture at wilting point (θ_{pwp}), root depth (D), electrical conductivity (EC), PH, nitrogen total (N), phosphorus (P) and potassium (K) were 1.3 g cm^{-3}, 25%, 10%, 0–60 cm, 1.7 ds m^{-1}, 7.5, 0.045%, 17 mg kg^{-1} and 265 mg kg^{-1}, respectively.

A pre-sowing irrigation was applied for 10 days and 60 kg ha N was applied to the soil before planting. Each plot consisted of 6 rows (5 × 2.7 m) and the row spacing was 45 cm. Seeds were sown at a depth of 3–4 cm with a density of 75 seeds m^{-2} on 8 March (2007, 2008). Following sowing, the first irrigation was applied.

Table 1 Irrigation regimes based on evaporation from a class A pan and equivalent moisture percentage and moisture depletion in the soil

Percentage soil moisture depletions of available water (%)	Pre-irrigation soil moisture (%)	Accumulative evaporation from the evaporation pan (mm)	Treatment
60	16	70	I_{60}
75	14	105	I_{75}
90	12	140	I_{90}

Table 2 Number of irrigations and total volume of water applied per year for each irrigation regime

I_{60}		I_{75}		I_{90}	
Num.	Vol.	Num.	Vol.	Num.	Vol.
16	10078	12	7559	8	5040

Soil samples were collected from a soil depth of 0–60 cm and the soil water content was determined. The irrigation depth was determined based on pre irrigation moisture and soil depth according to the following equation [15]:

$$d = (\theta_{Fc} - \theta_i)/100 \times \rho_b \times D$$

In this equation, θ_{Fc} and ρb represent for soil moisture percentage by weight at field capacity (25% for sampled soil) and soil bulk density in g cm^{-3} (1.4 g cm^{-3} for sampled soil), respectively. Then, volume of irrigation water (m^{3}ha^{-1}) was calculated by the equation, V = (d/100) 10000 m^2. Determined irrigation volumes with this method, were delivered to the plots by irrigation counter and pump (Table 2).

Full irrigation continued until full seedling establishment had occurred at about 30 days after planting, then irrigation treatments started and continued until crop maturity. Irrigation regimes were started from seedling establishment until full maturity. Four center rows of each plant were harvested at full maturity stage. Seeds were cleaned, dried and used for further analysis.

Table 3 summarizes the average temperatures, relative humidity and rainfall data in 2007–2008.

Oil Extraction

Seeds of the genotypes were dried at 40 °C for 4 h, using a ventilated oven, to a moisture content of about 5%, and were then ground with a blender. Ten grams of ground seeds were used to extract the oil, using petroleum ether for 6 h in a Soxhlet system according to the AOCS method [16, 17] and then the oil content as a percentage was calculated for each sample.

Fatty Acid Profiling

The oil sample of each accession was converted to fatty acid methyl esters (FAME) according to the AOCS method [16, 17]. Samples of 350 mg oil were treated with 7 ml of 0.5 M (mol l^{-1}) sodium methylate in methanol and heated at its boiling temperature for 10 min and then 5 ml of Boron tri-fluoride in methanol was added and heated again

Table 3 Average monthly climatic data during the 2007 and 2008 growing season

Year	Month	Average temperature (°C)	Relative humidity (%)	Rainfall (mm)
	Jan	−1	68	7.1
	Feb	6	52	13.8
	Mar	9	48	35.2
	Apr	15.5	47	42.8
	May	21.5	39.5	16.4
2007	Jun	55.5	28.5	1.1
	Jul	69	84	0
	Aug	27.5	26.5	0
	Sep	21.5	25	0
	Oct	17	37	0
	Nov	11.5	34.5	2.3
	Dec	5	52	12.9
	Jan	−2	65	7.5
	Feb	5	50	12.5
	Mar	11	42	34
	Apr	16.5	43	40
	May	26	36	14
2008	Jun	58	25	1
	Jul	65	81	0
	Aug	26	26	0
	Sep	21	23	0
	Oct	15	39	0
	Nov	10	34	2
	Dec	5	50	14

for 2 min. After that, 6 ml of GC-grade hexane was mixed in and heated for 2 min. Finally, 50 ml saturated saline water was added and samples were vigorously shaken for 1 min at room temperature. The upper phase was taken and used for gas chromatography. The methyl esters of the fatty acids (0.5 µl) were analyzed in a Chrompack CP 9001 series gas chromatograph (Chrompack, Middelburg, The Netherlands) equipped with a flame ionizing detector (FID) and a fused silica capillary column (CP-Sil 88, 50 m × 0.25 mm i.d.; film thickness = 0.2 µm). This process was operated at an oven temperature of 120 °C, which was then raised to 220 °C at a rate of 3.5 °C min^{-1} and then kept at 220 °C for 15 min. The injector and detector temperatures were 250 °C. The carrier gas was nitrogen at a flow rate of 4.93 ml min^{-1} and split ratio was 21.28 ml min^{-1}. Peak identification was performed by comparing the relative retention times with those of a commercial standard mixture of FAME.

The fatty acid content of palmitic (C16:0), stearic (C18:0), oleic (C18:1) and linoleic (C18:2) were determined using a computing integrator and shown as a percentage of the oil.

Statistical Analysis

Data of oil content and fatty acid composition were subjected to analysis of variance (ANOVA) using GLM procedure of SAS statistical program [18] and MSTAT-C procedures. Treatment means were separated using the least significant difference (LSD) test ($p < 0.05$).

Results and Discussion

The results showed that there were significant differences between irrigation regimes and cultivars for seed oil and fatty acid composition (Table 4). The cultivar–drought interaction effects for oil contents were significant suggesting both genetic and drought effects. The oil contents of IL111, PI and Kuseh were 30.73, 27.63 and 25.23% under non-stress conditions (I_{60}), respectively (Table 5). The ranges from 20–45%, 22–32%, 29.0–35.3% and 21–33% between safflower cultivars or accessions have been reported by others [1, 14, 19, 20]. Oil contents of safflower cultivars ranged from 24.53 to 28.47% in winter sowing

Table 4 Analysis of variance for oil content and main fatty acids in three irrigation regimes and with three cultivars of safflower

Source of variation	df	Oil	C16:0	C18:0	C18:1	C18:2
Block (*B*)	2	2.34^{**}	3.00^{**}	2.99^{**}	3.36^{**}	2.70^{**}
Irrigation (*I*)	2	15.13^{***}	2.83^{**}	20.81^{***}	7.51^{***}	12.39^{***}
*B***I*	4	0.11	0.44	1.00	0.03	0.03
Cultivar (C)	2	85.33^{***}	7.56^{***}	32.07^{***}	14.93^{***}	60.24^{***}
C**I*	4	4.92^{***}	4.08^{***}	21.69^{***}	5.84^{***}	33.61^{***}

*, ** and *** significant at 0.05, 0.01 and 0.001 levels of probability, respectively

Table 5 Oil content (%) of safflower cultivars as affected by irrigation regimes

Irrigation regimes (%)	Cultivars			Mean
	KUSEH	PI	IL111	
I_{60}*	25.23^{d}*	27.63^{b}	30.73^{a}	27.87^{A}**
I_{75}	23.23^{e}	26.13^{c}	30.33^{a}	26.23^{B}
I_{90}	22.40^{f}	23.63^{e}	28.03^{b}	24.32^{C}
Mean	23.62^{C}**	25.80^{B}	29.70^{A}	
LSD	Variety:0.43		Water stress:0.43	

*Means within a row and column with the same letters are not significantly different at the 5% level

**Means within column or row with the same letters are not significantly different at 5% level

I_{60}, I_{75} and I_{90}, 60, 75 and 90% soil moisture depletions of available water

and 21.23–25.76% in spring sowing in Turkey [5]. Oil contents of 29.20–34.99, 20.04–30.80 and 15–28.80% were reported in *Carthamus tinctorius*, *C. oxyacantha*, and *C. lanatus*, respectively indicating wide variation in oil contents within and between accession and species of Carthamus genus [21]. IL111, PI and Kuseh are spiny, semi-spiny and spineless cultivars, respectively. Cultivars with reduced or no spines were reported to have a lower oil content than spiny types [8, 22]. Thus, our results are in accordance with the others.

As drought levels increased, the oil content decreased, the overall reduction was about 13% (Table 5). Reductions in oil content of soybean and groundnut were also reported to take place under drought stress [11, 13]. The highest oil content was produced by IL111 under I_{60}, while the lowest was produced by Kuseh under I_{90}. The oil contents of Kuseh, PI and IL111 were reduced by 9, 6 and 1% under mild and 13 and 17 and 8% under severe drought stress, respectively. This suggests that cultivars responded differently to the drought. With a few exceptions, the range of oil contents of our cultivar was within the ranges of others. Any differences between oil contents of the cultivars reported here and elsewhere were mainly due to the genes that control production of oil in these cultivars [8, 23]. However, environmental conditions and management practices may also affect the oil content of the cultivars [4, 20].

Water deficit was reported to reduce yield, yield components and oil content of safflower cultivars [24]. They [24] used normal irrigation or withholding water at budding, flowering and maturity stages. Arak contained the highest oil content followed by Esfahan and FO_2 under stress and non-stress conditions, respectively. Three cultivars of safflower were also compared under five irrigation regimes [25]. S-451 produced the highest oil content following by Girard and Finch, respectively. There were no significant differences between irrigation regimes.

The oil content of canola cultivars was not affected by moderate drought stress, while it was reduced significantly under severe drought. There were no differences between the cultivars; however, there was interaction between cultivar and irrigation regime on the oil content [25]. The effect of three irrigation regimes and three irrigation systems on yield, yield components and oil content of sesame were also compared [26]. The results showed that as drought levels increased, yield, yield components and oil content were reduced, and controlled surface irrigation was superior to sub-surface drip and surface drip irrigations.

Furthermore, four canola cultivars were compared under three irrigation regimes. Yield, yield components and oil content across all cultivars were reduced as the drought level increased [27]. However, there were significant differences between the cultivars. They found that the earliest maturity cultivars with a drought escape mechanism were the most drought tolerant followed by mid-and late maturity cultivars, respectively.

Under our conditions, Kuseh, IL111 and PI were mature at 105.2, 98.7 and 98.5 days, respectively and the irrigation regimes had no significant effect on maturity dates [28]. In addition, four canola cultivars under four drought levels showed significant variations in their yield [29]. They ranked Hayola 401, Hayola 308, Option and RGS as drought tolerance, respectively. Oil content of IL111, PI and Kuseh were reduced by 1 and 7, 5 and 14, and 8 and 11% under moderate and severe stress, respectively. Thus, based on the percentage oil content reduction, IL111 was the most tolerant cultivar to drought under our conditions.

The palmitic acid contents of Kuseh, PI and IL111 were 3.02, 4.92 and 2.21 under normal conditions, respectively. In Turkey, palmitic acid contents of 6.07–6.32% [5] and 6–8% in standard safflower cultivars [30] have been reported. Palmitic acid contents of 4.7, 6.6 and 6% have also been reported for very high linoleic and intermediate oleic acid and high stearic acid contents selected lines of safflower [30], respectively. Dincer. Yenice and 5–154 cultivars contained 11.9–16.0, 11.3–13.4 and 11.3–11.4% palmitic acid, respectively in Turkey [22]. The range of 5.48–8.78% palmitic acids contents were also reported between and within the *Carthamus* genus [21].

Palmitic acid content of the cultivars was reduced from 2.37 to 1.47% as drought levels increased from I_{60} to I_{90}, a reduction of about 60% (Table 6). Palmitic acid contents of Kuseh, PI and IL111 were reduced by 27 and 53, 100% under mild and 100, 194 and 116% under severe drought stress, respectively. PI contained the highest amount of palmitic acid under I_{60}, while IL111 produced the lowest under I_{90} (Table 6). The percentage reductions in palmitic acid were 51, 65 and 53% for Kuseh, PI and IL111, respectively. On average, the palmitic acid content of PI was highest followed by Kuseh and IL111, respectively. In contrast, an increase of 0.39–0.74% in the palmitic acid content of sunflower under drought conditions has been reported by others [10]. The results showed that palmitic acid contents of our cultivars were lower than the palmitic acid contents of reported cultivars under both normal and stress conditions.

Previous researchers imposed water stress 7 days before and up to 12 days after flowering, whereas we imposed water stress throughout of the plants' life. Therefore, the differences between our results and previous report could be due to species and experimental conditions.

The highest stearic acid content was record recorded in PI (10.97%) followed by IL111 (6.86%) and Kuseh (6.19%), respectively (Table 6). There was no difference between IL111 and Kuseh. Dincer, Yenice and 5–154

Table 6 Fatty acid composition (%) of safflower cultivars as affected by irrigation regimes

Fatty acids	Irrigation regimes (%)	Cultivars			Means
		KUSEH	PI	IL111	
Palmitic ($C_{16:0}$)	I_{60}*	3.02^{bc}*	4.92^{a}	2.21^{cde}	3.31^{A}**
	I_{75}	2.37^{bcd}	3.20^{b}	1.08^{f}	2.37^{AB}
	I_{90}	1.47^{ef}	1.69^{def}	1.02^{f}	1.22^{B}
	Mean	2.29^{B}**	3.27^{A}	1.44^{C}	
	LSD	Varieties:0.44		Water stress:0.87	
Stearic ($C_{18:0}$)	I_{60}	6.19^{c}	10.97^{a}	6.86^{c}	7.95^{A}
	I_{75}	6.00^{c}	9.82^{b}	5.88^{c}	7.05^{B}
	I_{90}	3.86^{d}	4.28^{d}	1.89^{e}	3.19^{C}
	Mean	5.35^{B}	8.36^{A}	4.88^{B}	
	LSD	Varieties:0.48		Water stress:1.30	
Oleic ($C_{18:1}$)	I_{60}	23.67^{a}	21.60^{cd}	22.06^{bc}	21.35^{A}
	I_{75}	22.63^{b}	19.15^{e}	19.78^{e}	20.14^{B}
	I_{90}	20.75^{d}	19.00^{e}	19.36^{e}	19.05^{C}
	Mean	22.35^{A}	19.92^{B}	20.40^{B}	
	LSD	Varieties:0.82		Water stress:0.45	
Linoleic ($C_{18:2}$)	I_{60}	72.35^{b}	71.96^{bc}	74.79^{a}	72.65^{A}
	I_{75}	68.38^{d}	66.46^{e}	72.68^{b}	68.37^{B}
	I_{90}	65.56^{e}	65.79^{e}	71.10^{c}	67.28^{C}
	Mean	68.76^{B}	68.07^{C}	72.86^{A}	
	LSD	Varieties:0.62		Water stress:0.25	

*Means within rows and columns with the same letters are not significantly different at 5% level (for each fatty acid)

**Means within columns or rows with the same letters are not significantly different at 5% level (for each fatty acid)

I_{60}, I_{75} and I_{90}, 60, 75 and 90% soil moisture depletions of available water

cultivars of safflower showed 1.8–6.7, 0.2–1.7, 0.3–8.4% stearic acid contents under different flower formation [22]. The stearic acid content in safflower cultivars ranged from 2.06 to 2.24% in Turkey [5], while stearic acid content in standard safflower cultivar ranged from 2 to 3% [30]. However, very high and high linolenic acid, high and intermediate oleic acid and high stearic acid safflower cultivars contained 2, 3, 2 and 8% stearic acid [4]. The stearic acid content of Kuseh, PI and IL111 were reduced by 3 and 37, 10.5 and 61 and 14 and 72% under mild and severe drought stress, respectively. However, there were no differences between 2-, 6- and 9-day irrigation intervals in the stearic acid content, but an increase was observed with 12-day irrigation intervals in soybeans [31].

Stearic acid content was reduced as drought levels increased. The average stearic acid reduction was about 60% (Table 6). This could be due to irrigation level, genetic differences (species and cultivar) and environmental conditions [13]. The stearic acid contents of Kuseh, PI and IL111 were reduced by 3 and 11, 16% under mild and 60, 156 and 262% under severe drought stress, respectively. Ther highest and lowest stearic acid contents were recorded in PI under I_{60} and IL111 under I_{90}, respectively. A reduction of up to 1.33% in the stearic acid content of sunflower has been reported [10], while a significant increase in the stearic acid content of peanut seed under drought has been reported by others [13].

The oleic acid contents of Kuseh, PI and IL111 were 23.67, 21.60 and 22.06%, respectively (Table 6). Oleic acid contents of 27.8–30.7, 24.5–37.8 and 35.4–44.7% have been reported for Dincer, Yenice and 5–154 safflower cultivars, respectively [22]. In Turkey, the oleic acid content of safflower ranged from 17.51 to 19.38% [5] while an oleic acid content of 16-20% has been reported elsewhere [30]. The highest oleic acid content was produced by IL111 under I_{60}, while the lowest was produced by PI under I_{90} (Table 6). The oleic acid content was reduced from 21.35% to 19.05% as drought levels increased from I_{60} to I_{90} indicating a reduction of about 11% (Table 6). However, there was significant difference between the cultivars. The oleic acid contents of Kuseh, PI and IL111 were reduced by 5–12, 12–14 and 13–14% under mild and severe water stress, respectively (Table 6). The oleic acid contents of Kuseh, PI and IL111 were reduced by about 12, 9 and 12% when drought levels increased from I_{60} to I_{90}, respectively (Table 6). A reduction of 4–14% in the oleic content of sunflower but an increase in the oleic acid concentration of groundnut under drought stress have also been reported by others [10, 13]. On the other hand, an increase in oleic acid in high oleic sunflower hybrids, but a reduction in oleic acid content of standard hybrids have been reported as well [9]. In addition, severe drought stress reduced the oleic acid content of canola by 3.8% in a Mediterranean-type environment [32].

The linoleic acid contents of Kuseh, PI and IL111 were 72.35, 71.96 and 74.79% respectively under normal conditions (Table 6). It was reported that very high and high linoleic acids, high and intermediate oleic and high stearic acids cultivars of safflower contained 6, 18, 78, 47 and 4% oleic acid contents, respectively [22]. Safflower cultivars contained 71–75% linoleic acid [30], while very high and high linoleic acid, high and intermediate oleic acid and high stearic acid content safflower cultivars contained 88, 73, 16, 48 and 7% linoleic acids, respectively [4]. The linoleic acid contents of Turkish cultivars have been reported to be from 71.56 to 73.32% [5]. This showed that the linoleic acid content of our cultivars was within the range of Turkish cultivars. The linoleic acid content was reduced as the drought level increased, the reduction was only about 7% (Table 6). However, there was interaction between the cultivar and the irrigation regime. IL111 produced highest linoleic acid content followed by Kuseh and PI, respectively. Safflower oil and fatty acid content reduced according to levels of water deficit while, peanut linoleic acid content by reduced by end-of-season drought [13], which is in agreement with our results. In contrast, up to a 14% increase in linoleic acid content in sunflower under drought stress has been reported [10]. Under severe water stress, a reduction of 2.0% in the linoleic content of canola has also been reported in a Mediterranean-type environment [32].

The results showed that our cultivars were among low oleic, stearic and palmitic acid and standard linoleic type safflowers. This experiment showed that severe drought stress reduced palmitic, stearic, oleic and linoleic acids contents by 63, 59, 11 and 7%, respectively. Whereas, the difference, between the cultivars was 55, 9 and 4% for palmitic, stearic, oleic and linoleic acid contents, respectively. The results suggested that the choice of genotype was of less importance than environment.

The overall results showed that the oil content and the fatty acid composition varied between the safflower cultivars. Drought stress reduced the oil content and fatty acid composition and there was an interaction between cultivar and drought stress level to have an effect on oil content and fatty acid composition indicating that selection of more drought tolerance cultivars in relation to oil and fatty acids composition is possible. However, the reduction was up to 63% for palmitic acid, 72% for stearic acid, 10% for linoleic acid and 12% for oleic acid. Both stearic and palmitic acids are unhealthy saturated fatty acids, whereas oleic and linoleic acids are both unsaturated healthy fatty acids. Oleic acid has a very high stability, a bland flavor, good frying characteristics and a high temperature tolerance, while linoleic acid may reduce blood cholesterol [2, 19]. This dramatic and dynamic effect of drought on the quality of safflower oil seed which resulted in a huge reduction in saturated fatty acids content by drought suggested that imposing drought through proper irrigation regimes may enhance the quality of safflower oil seed. In addition, production of such an oil composition under our irrigation regimes reduces the need for a hydrogenation process which may otherwise produce undesirable trans-fat in the food leading to an increase in cholesterol and heart disease in humans [33].

Furthermore, higher oleic and linoleic acids and lower stearic and palmitic acids under drought stress, suggested that a more realistic response of the plants to drought should be sustained water stress since sustained water stress allows the plant to adapt to the drought and may a produce good quality crop [14].

The role of the oil and fatty acids composition of seeds in drought tolerance of the plant has not been confirmed by our study yet. However, changes and role of oil and fatty acids composition of aerial parts of the plant under drought have been investigated. Water stress may cause a reduction in the degree of unsaturation of fatty acids by inhibiting the biosynthesis or polyunsaturated fatty acids and denaturizing activities leading to a reduction in oil content and a change in oil composition [9].

A severe water deficit lowered the level of total lipids in the shoots of safflower. Galactolipids and phospholipids contents were also lowered significantly under drought. A reduction in galactolipids, the main chloroplastic lipids, under water stress, may affect photosynthesis because the structure of chloroplast membranes could be affected [34, 35].

Moderate water stress, however, increased the concentration of polar lipids indicating that mild water stress activates the biosynthesis of new membranes [35]. A decrease in unsaturated and an increased in saturated fatty acid contents of safflower shoots were also detected under water stress [35]. A decrease in polar lipids and an increase in neutral lipids contents especially triacylglycerols of safflower shoots were also observed [35].

An increase in palmitic and stearic acids contents and a decrease in total lipids and linoleic, oleic and linoleic fatty acids contents of *Phaseolus vulgaris* aerial parts have also been reported [36].

A reduction in polyunsaturated fatty acids contents has also been reported to induce metabolic changes in the cellular membranes while, increases in the saturated fatty acid contents enhanced rigidity in the cellular membranes leading to senescence and a reduction in the yield under water stress [36].

Furthermore, acetyl COA carboxylase, a key enzyme of lipid biosynthesis, was reported to enhance only the tolerant peanut accession suggesting a fatty acid mediated drought tolerance [36]. Based on the results of previous studies reviewed here, the plant may tolerate water stress by structural modifications allowing plants to adjust the

fluidity of their membranes by an appropriate rearrangement of their glycerolipids and adjustment of their unsaturated fatty acid composition [36].

The results showed that stearic and palmitic acids were significantly reduced in seed oil of safflower cultivars under water stress. However, palmitic and stearic acid of aerial parts of safflower and other plant species were reported to increase under drought stress. This suggests that under water stress, plant may allocate its saturated fatty acids to aerial parts instead of the seeds resulting in an increase in drought tolerance.

Thus, this investigation used three irrigation regimes throughout the plants' life since in dry and semi-dry areas, growing plants without irrigation especially in the summer is not possible. Therefore, deficit irrigation whereby water supply is reduced below maximum levels and mild stress is possible in order to save water [37]. Consequently, water stress affects the physiology, anatomy, morphology and biochemistry of the plants leading to a reduction in oil content and oil composition of seeds of a crop grown under drought stress. Several strategies such as a conventional screen in breeding and genetics engineering for producing drought resistant plants and crop management such as sowing time, weed control and nutrients may be used to produce a better crop under drought stress. Here, it is suggested that a proper irrigation regime, throughout the life of the plant rather than short-term withholding of water at specific growth stages, may cause a small reduction in total oil content, but dramatically increase the quality of the oil composition of safflower.

Conclusion

Drought caused areduction in the oil content and composition of the seed safflower cultivars. The total oil content was reduced by about 13%, while palmitic and stearic acids contents were reduced by 60 and 70% by drought stress, respectively. Reductions in linoleic and oleic acid content was about 7 and 11%, respectively. Therefore, the decrease was mainly due to a reduction in saturated fatty acids contents indicating that the oil quality of safflower seed may enhance sustainability under proper irrigation regimes. Consequently, a proper irrigation regime through out the life of the plant may cause small a reduction in the total oil content, but it dramatically increases the quality of the oil composition of safflower seeds.

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