Salinity Effects on Yield and Oil Quality of High-Linoleate and High-Oleate Cultivars of Safflower (*Carthamus tinctorius* L.)

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Safflower (*Carthamus tinctorius* L.) is a salt-tolerant crop, and salinity does not affect the quality of the oil of standard cultivars. A small-plot study was conducted to determine whether differences in salt tolerance exist among three standard cultivars and one high-oleate cultivar of safflower. Increasing salinity in irrigation water decreased seed yield, plant height, and oil content in all entries. Growth rate increased with increasing salinity and was indicated by earlier maturity dates in the salt-stressed plants. Fatty acid composition of high-linoleate safflower oil was not altered with increasing salinity. Fatty acid composition was altered in the high-oleate cultivar, resulting in depressed oleic acid content in the oil. Cl, Ca, and Na increased while P and Mg decreased in leaf tissues with increasing salinity levels.

Common commercial safflower with oil containing about 80% linoleic acid (high linoleic) (Knowles et al., 1965) is the leading type of safflower grown; about 80% of all safflower grown in the United States is this type. Another type of safflower (high oleate), with oil containing about 80% oleic acid (Knowles et al., 1965), may be of increasing interest because it is monounsaturated. This oil has been shown to reduce low-density lipoprotein (LDL) cholesterol levels (Smith, 1985; Mattson and Grundy, 1985) and is stable to oxidation (Purdy, 1985) and high temperatures (Fuller et al., 1967; Knowles, 1969). Oil high in oleic acid does not polymerize as readily under high-temperature regimes as does oil high in polyunsaturates.

Safflower has been shown to be highly salt tolerant in terms of yield and oil production and therefore can be grown on marginal land (Francois and Bernstein, 1964; Kurian and Iyengar, 1972; Devi et al., 1980; Ahmed et al., 1977). Salinity was shown not to affect the fatty acid composition of the oil (Yermanos et al., 1964) of standard safflower. However, increasing salinity has been shown to decrease germination percentage in safflower (Francois and Bernstein, 1964; Ghorashy et al., 1972), which was determined to be only half as tolerant during germination as during later stages of growth.

This study was conducted to detemine whether differences in salt tolerance or salinity effects on seed and oil yield and composition exist among three common and one high-oleate type of safflower.

MATERIALS AND METHODS

Raised beds were prepared in 12 field plots (6.6 × 6.6 m) to accommodate four salinity treatments. Each plot was divided into four subplots and planted with four safflower cultivars: Oleic Leed (high-oleate type), VFSTP-1, S296, and S400. In 1983, seeds were obtained from Dr. A. L. Urie at University of California, Davis, whereas in 1984 seed was from control plots of the 1983 trial. Seeds were germinated and established 2–3 weeks with nonsaline water [electrical conductivity (EC) of approximately 0.9 dS/m (0.9 mmho/cm)] prior to salt treatment. Differential salinization levels (Table I) were applied by flood irrigation. Treatment salts were applied as a 2:1 molar ratio of NaCl and $CaCl_2$ added to the irrigation water to give EC values of about 0.9, 7.5, 13.5, and 20.5 dS/m, corresponding to control, low, medium, and high salt treatments. These treatments were selected on the basis of previous studies (Francois and Bernstein, 1964; Yermanos et al., 1964). Prior to planting, P_2O_5 was incorporated into each plot at a rate of 16.8 g/m^2. Trials were carried out during 1983 and 1984.

Table I. Electrical Conductivity (EC) Measurements

	1983			1984		
EC, dS/m	appl	EC_e[a]	EC_e[b]	appl	EC_e[a]	EC_e[b]
0.9	0.95	1.43	1.61	0.81	1.32	1.36
7.5	7.83	5.32	6.29	7.59	5.61	6.14
15.5	14.03	10.50	12.41	13.85	7.89	8.86
20.5	19.71	13.38	16.01	20.66	12.26	14.34

[a] Mean EC of saturated-soil extracts (dS/m) taken before anthesis. [b] Samples taken before harvest.

Irrigations were scheduled by tensiometer readings, and total water applied was 408 and 572 mm during the 1983 and 1984 seasons, respectively. Irrigation water was amended with 0.1 g/L KNO_3 and 0.1 g/L $Ca(NO_3)_2$.

Safflower was planted on 6-25-83 for the first trial, differential salinization was initiated on 7-13, and plants were harvested 9-12 to 9-19-83. Average daytime temperature during the 90-day growing season was 32.8 °C and ranged from 21 to 43 °C. Average nighttime temperature was 18.8 °C and ranged from 13 to 22 °C.

Planting date for the second trial was 4-4-84. Salt treatments were initiated on 4-17, and plants were harvested 7-23 to 8-15-84. Average daytime temperature was 32.5 °C and ranged from 19 to 45 °C. Average nighttime temperature was 16 °C and ranged from 9 to 22 °C. The growing season was about 122 days.

Soil samples were taken at 15-cm increments to a depth of 60 cm in each plot prior to anthesis and just before harvest during both trials. Average EC values were determined on saturated-soil extracts (EC_e).

A composite leaf sample of each cultivar from each plot was collected on 8-17-83, dried, ground to 20 mesh (in a Wiley mill), and analyzed for mineral content. A subsample was dry-ashed and dissolved (Horowitz, 1960), and Cl was determined on an automatic choride titrator by standard procedures (Cotlove, 1964). Phosphorus was estimated according to the procedures of Allen (1940). Another subsample was dry-ashed (Issac and Johnson, 1975) prior to determination of Mg, Ca, K, Na, and N. These elements were determined on an atomic absorption spectrophotometer (Perkin-Elmer, 1982).

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Table II. Seed Yield[a] per Plot

1983 Harvest

	cultivars pooled[b]			
	primary heads		secondary heads	
EC, dS/m	g/plot	% control	g/plot	% control
0.9	64.0 a[c]	100	194.7 ab	100
7.5	90.0 a	141	220.8 a	113
13.5	53.2 a	81.3	115.1 b	59.1
20.5	19.3 b	30.2	28.3 c	14.5

	tertiary heads							
	oleic leed		VFSTP-1		S296		S400	
EC, dS/m	g/plot	% control	g/plot	% control	g/plot	% control	g/plot	% control
0.9	19.5 ax	100	57.4 awx	100	107.3 aw	100	69.5 aw	100
7.5	7.9 ax	40.5	68.4 aw	119	65.0 abw	60.6	78.3 aw	113
13.5	1.1 bx	5.6	33.3 aw	58.0	25.0 bw	23.3	52.4 aw	75.4
20.5	0.1 cx	0.51	6.6 bw	11.5	4.3 cw	4.0	8.4 bw	12.1

1984 Harvest

	cultivars[b]			
	primary heads		secondary heads	
EC, dS/m	g/plot	% control	g/plot	% control
0.9	267.7 a	100	630.4 ab	100
7.5	287.2 a	108	744.0 a	118
13.5	184.6 b	69.0	425.5 b	67.5
20.5	75.9 c	28.4	150.0 c	23.8

	tertiary heads							
	oleic leed		VFSTP-1		S296		S400	
EC, dS/m	g/plot	% control	g/plot	% control	g/plot	% control	g/plot	% control
0.9	162.4 aw	100	135.4 awx	100	91.6 ax	100	148.9 aw	100
7.5	120.3 awx	74.1	142.0 aw	105	87.1 ax	95.1	99.9 abwx	67.1
13.5	33.7 bx	20.8	83.0 bw	61.3	55.0 awx	60.0	63.0 bw	42.3
20.5	3.2 cw	2.0	14.4 cw	10.6	13.0 bw	14.2	14.6 cw	9.8

[a] Weight in grams per plot, averaged over three plots. [b] No significant interaction between cultivars and treatments. [c] Values followed by different letters are significantly different at the 5% level. Key: abc, comparisons between treatments within cultivars; wx, comparisons between cultivars within treatments.

Safflower seed samples were cleaned in a vertical-flow air classifier. Oil was obtained by grinding cleaned seed in hexane in a homogenizer and then extracting by Soxhlet refluxing with hexane for 6 h. After the solvent was evaporated at room temperature, the oil was dried in a vacuum oven at 100 °C. Methyl esters were prepared by boiling the seed oil with methanolic NaOH followed by BF_3–CH_3OH (AOAC, 1980) and recovered by heptane extraction. Methyl esters were analyzed by gas chromatography utilizing a fused silica capillary column, 0.15 mm × 15 m, operated isothermally at 200 °C with split injection and flame ionization detection. Peaks were identified by comparison of retention times with known standards and by cochromatography. Amounts of the fatty acid esters methyl palmitate, stearate, oleate, and linoleate present in the sample were determined by automatic integration, and the percent by weight of each component was calculated.

Mature seed from the primary, secondary, and tertiary heads from each subplot were harvested and analyzed separately for yield components and oil characteristics. Experimental data were subjected to split-plot analyses of variance to determine significant irrigation treatment and cultivar differences. Means different at the 5% level of probability were identified by calculating least significant difference (LSD) values (Milliken and Johnson, 1984) and assigning letters to the means presented in tables. Seed further cleaned by air classification was also subjected to statistical analysis. The combined yield data for primary, secondary, and tertiary heads for each cultivar were plotted to present overall yield. LSD values were not determined for these data because some of the data were transformed in the initial statistical analyses to calculate LSD values.

RESULTS

Plot Yield. Average yields of clean seed per plot for each cultivar were decreased by moderate- to high-salinity treatment in 1983 and 1984 (Figure 1). In most instances, yield increased at the lowest level of added salinity treatment but decreased significantly with increasing salinity. Average yields in 1984 were approximately double those of 1983. Factors that may have contributed to this effect include seed age and length of growing season. Seed yields of all cultivars during the shorter 1983 growing season were considerably less than in 1984. Correspondingly, increased vigor in the newly regenerated seed lines probably contributed to higher yields.

Overall, cultivars responded similarly to increasing salinity. There was no significant interaction between cultivars and treatments for primary or secondary heads in either 1983 or 1984; therefore, cultivar results were pooled to determine the effect of salinity on the whole plot (Table II). Significant interactions occurred between the cultivars and treatments for tertiary head yield; therefore, these were disaggregated. Tertiary heads were more affected by salinity treatment than other head locations perhaps because of earlier maturity of salinity-stressed plants or accumulative salt effects with time. Secondary heads were more affected by salinity than primary heads in 1983, but both head types responded about the same in terms of percent yield reduction in 1984. Although yields of pri-

Table III. Seed Yield[a] per Plant

	oleic leed		VFSTP-1		S296		S400	
EC, dS/m	g/plant	% control	g/plant	% control	g/plant	% control	g/plant	% control
				1983 Harvest				
				Primary				
0.9	0.160 ax[b]	100	0.480 bw	100	0.474 abw	100	0.391 abx	100
7.5	0.162 ay	101	0.818 aw	170	0.561 ax	118	0.517 ax	132
13.5	0.060 ay	37.5	0.618 abw	129	0.334 bcx	70.5	0.407 abx	104
20.5	0.009 ax	5.6	0.242 cw	50.4	0.137 cwx	28.9	0.218 bw	55.8
				Secondary				
0.9	0.572 ax	100	1.305 aw	100	1.470 aw	100	1.206 aw	100
7.5	0.336 ay	58.7	1.961 aw	150	1.406 ax	95	1.515 awx	126
13.5	0.083 ax	14.5	1.316 aw	101	0.940 abw	63.9	0.950 abw	78.8
20.5	0.003 aw	0.52	0.364 bw	27.6	0.278 bw	18.9	0.365 bw	30.3
				Tertiary				
0.9	0.101 ax	100	0.372 aw	100	0.538 aw	100	0.309 awx	100
7.5	0.039 ax	38.6	0.452 aw	122	0.293 abw	54.5	0.314 aw	102
13.5	0.005 bx	5.0	0.194 aw	52.2	0.144 bw	26.8	0.235 aw	76.1
20.5	0.000 cx	0	0.048 bw	12.9	0.023 cw	4.3	0.038 bw	12.3
				1984 Harvest				
				Primary				
0.9	0.995 aw	100	1.013 aw	100	0.882 aw	100	1.002 aw	100
7.5	0.922 abw	92.7	0.993 aw	98	0.924 aw	105	0.990 aw	98.8
13.5	0.545 bcx	54.8	0.699 awx	69.0	0.674 awx	76.4	0.739 aw	73.8
20.5	0.258 cx	25.9	0.315 bx	31.1	0.457 bwx	51.8	0.485 bw	48.4
				Secondary				
0.9	2.938 aw	100	2.855 aw	100	1.512 abx	100	2.000 axw	100
7.5	2.860 aw	97.3	2.566 abw	89.9	2.170 aw	144	2.390 aw	120
13.5	1.073 bw	36.5	1.816 bw	63.6	1.647 abw	109	1.630 abw	81.5
20.5	0.382 bw	13.0	0.681 cw	23.9	0.909 bw	60.1	0.928 bw	46.4
				Tertiary				
0.9	0.654 aw	100	0.523 aw	100	0.319 ax	100	0.521 aw	100
7.5	0.438 bwx	67.0	0.498 aw	95.2	0.263 aby	82.4	0.320 bxy	61.4
13.5	0.122 cx	18.7	0.387 aw	74.0	0.178 bx	55.8	0.208 bx	39.9
20.5	0.019 dx	2.9	0.089 bw	17.0	0.053 cwx	16.6	0.077 cw	14.8

[a] Weight of clean seed in grams per plant. [b] Values followed by different letters are significantly different at the 5% level. Key: abcd, comparisons between treatments within cultivars; wxyz, comparions between cultivars within treatments.

Table IV. Height (cm) per Plant Cultivar Data Pooled

EC, dS/m	1983[a]	1984[b]	EC, dS/m	1983[a]	1984[b]
0.9	69.1	98.2	13.5	63.9	72.6
7.5	68.1	87.6	20.5	56.7	58.4

[a] 5% LSD, 5.9. [b] 5% LSD, 9.0.

mary and secondary heads appeared to be higher in low-salt treatments than the control, the increase was not statistically significant. Tertiary head yield was generally reduced by low salt as compared with the control; however, VFSTP-1 showed an increase in both years and S400 showed an increase in 1983, but not in 1984.

Yield per Plant. Secondary heads yielded more seed per plant than primary or tertiary heads of each cultivar (Table III). Primary head yields seemed to be the least affected by salinity in 1983 whereas the difference between yield decrease in primary vs secondary heads in 1984 was minimal and probably not significant. The greatest seed yield decrease in tertiary heads occurred in high-salt treatments of all cultivars.

Oleic Leed was the lowest yielding safflower cultivar on a per plant basis. Significant differences in yield among the four salinity levels were not apparent for this variety in 1983 except for tertiary heads. Plant stand and plant vigor were below optimum, even under nonsaline conditions.

On the basis of yield, the most salt-tolerant cultivar in 1983 was S400 followed by VFSTP-1, S296, and Oleic Leed. In 1984, the ranking was S296, S400, VFSTP-1, and Oleic Leed.

Plant Height. There were no significant interactions between cultivars and treatments for plant height; therefore, cultivar results were pooled (Table IV). Plant height decreased with increasing salinity level. The 1984 plants were taller than the 1983 plants and significant differences between the control and saline treatments appeared at medium salinity in 1984 whereas significant differences were apparent only at the high salt level in 1983.

Minerals. There were no significant interactions between cultivars and treatments for mineral composition except with Mg (Figure 2). Cultivar data for other min-

Table V. Elemental Composition of Leaf Material[a] Cultivar Data Pooled

EC, dS/m	chloride	phosphorus	magnesium[b]	calcium	potassium	sodium	nitrogen
0.9	562 b[c]	82 a	94	365 b	593 a	44 b	2257 a
7.5	681 ab	74 ab	79	405 ab	540 a	52 b	2186 a
13.5	791 ab	67 ab	61	465 ab	545 a	69 ab	2164 a
20.5	1000 a	57 b	53	570 a	491 a	145 a	1886 a

[a] Values are im millimoles/kilogram dry weight. [b] No significant interactions between cultivars and treatments for elements except Mg. See Figure 3. [c] Values followed by different letters are significantly different at the 5% level.

Table VI. Safflower Oil Composition[a] Combined Head Location

	percent oil[a]							
	1983				1984			
EC_e, dS/m	oleic leed	VFSTP-1	S296	S400	oleic leed	VFSTP-1	S296	S400
0.9	31.32[b] aw	33.23 awx	35.47 ax	35.60 ax	38.36 aw	35.03 ax	36.98 awx	39.99 aw
7.5	28.30 abw	33.83 ax	34.68 ax	36.58 ax	36.19 aw	35.51 aw	36.28 aw	38.26 aw
13.5	25.78 bw	30.97 ax	30.52 bx	31.90 bx	29.74 bw	30.16 abwx	29.60 bw	33.08 abx
20.5	25.20 bw	27.21 bw	27.87 bw	29.11 bw	28.18 bw	25.11 bw	26.15 bw	30.38 abw

[a] Values expressed as percent by weight on an as is basis. [b] Values followed by different letters are significantly different at the 5% level. Key: ab, comparisons between treatments within cultivars; wx, comparisons between cultivars within treatments.

Table VII. Safflower Oil Composition[a] Combined Head Location

EC, dS/m	1983				1984			
				Linoleate[c]				
0.9	24.8 aw[b]	74.4 ax	73.7 ax	73.5 ax	36.17 aw	79.25 ax	76.96 ax	77.67 ax
7.5	27.1 abw	75.0 ax	73.9 ax	74.2 ax	39.34 aw	79.74 ax	77.02 ax	78.82 ax
13.5	31.5 abw	74.4 ax	73.1 ax	73.9 ax	40.81 aw	78.34 ax	75.26 ax	76.63 ax
20.5	34.9 bw	72.0 ax	72.7 ax	73.4 ax	48.34 bw	77.25 ax	74.41 ax	76.15 ax
				Oleate[c]				
0.9	66.7 aw	16.3 ax	16.4 ax	16.5 ax	56.71 aw	12.91 ax	14.38 ax	13.74 ax
7.5	64.7 aw	15.7 ax	16.0 ax	16.2 ax	53.45 abw	12.40 ax	14.09 ax	12.98 ax
13.5	59.8 axw	16.4 ax	16.7 ax	15.9 ax	51.29 bw	14.14 ax	15.79 ax	14.81 ax
20.5	55.9 aw	18.5 ax	16.8 ax	16.2 ax	43.43 cw	15.12 ax	16.35 ax	15.25 ax
				Stearate[c]				
0.9	2.07 aw	2.27 aw	2.43 aw	2.40 aw	1.83 aw	2.06 aw	2.11 aw	2.06 aw
7.5	1.70 aw	2.36 ax	2.26 ax	2.27 ax	1.70 aw	2.20 ax	1.92 awx	1.94 awx
13.5	1.74 aw	2.00 awx	2.22 ax	2.09 awx	1.59 aw	1.99 ax	1.81 awx	1.89 awx
20.5	2.17 aw	1.88 aw	2.19 aw	2.14 aw	1.72 aw	1.67 bw	1.74 aw	1.73 bw
				Palmitate[c]				
0.9	6.53 aw	7.00 aw	7.49 ax	7.67 abx	5.26 aw	5.88 awx	6.58 ax	6.49 awx
7.5	6.67 aw	6.90 aw	7.82 ax	7.41 ax	5.56 abw	5.62 aw	6.89 ax	6.32 awx
13.5	7.20 abw	7.14 aw	7.92 ax	8.11 abx	6.29 abwx	5.46 aw	7.24 ax	6.62 awx
20.5	7.92 bw	7.57 aw	8.28 aw	8.26 bw	6.48 bwx	5.99 aw	7.46 ax	6.90 awx

[a] Values expressed as percent by weight on an as is basis. [b] Values followed by different letters are significantly different in the 5% level. [c] Fatty acid values expressed as percent by weight of total fatty acid content. Key: ab, comparisons between treatments within varieties; wx, comparisons between varieties within treatments.

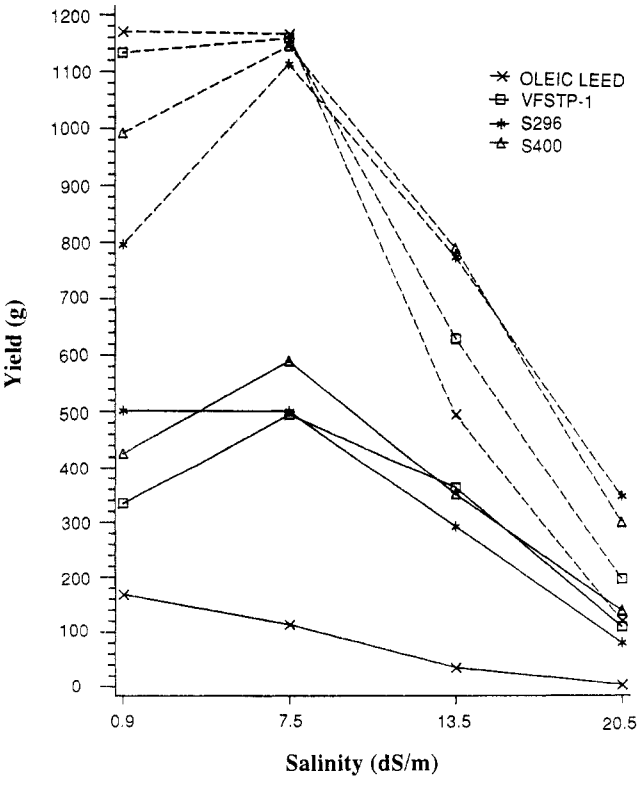

Figure 1. Total seed yield for each variety during 1983 (solid lines) and 1984 (dashed lines).

erals were combined and are presented in Table V. Leaf concentrations of P and Mg decreased with increasing salinity whereas Cl, Na, and Ca concentrations in leaf material increased with increasing salinity (Table V). Steady decreases in K and N occurred with increasing salinity but were not statistically significant.

Oil Composition. Soil salinity treatments above 13.8 dS/m caused significant reductions in oil content of safflower seed in most cultivars for both years (Table VI). No significant differences in oil yield were observed between control and low salt treatments. The combined reduction in oil yield and seed yield caused by salinity resulted in a great reduction in total oil yield. A general trend toward reduction of oleate and a corresponding increase in linoleate in Oleic Leed, the high-oleate cultivar, was noted with increasing salinity (Table VII). Oleate values of Oleic Leed were not significantly reduced by salinity in 1983, but were in 1984. Linoleate showed significant increases when the control was compared to the high-salt treatment. Total linoleate + oleate did not change appreciably with increasing salinity; thus, a fatty acid "shift" occurred as a result of the salinity treatment. Fatty acid composition of the high-linoleate cultivars, i.e. S400, S296, and VFST-P-1, remained stable throughout the four salinity treatments.

DISCUSSION

Increasing salinity reduced the number of flowering heads and the yield of seed per head as was also shown by Francois and Bernstein (1964). Maturation rates increased

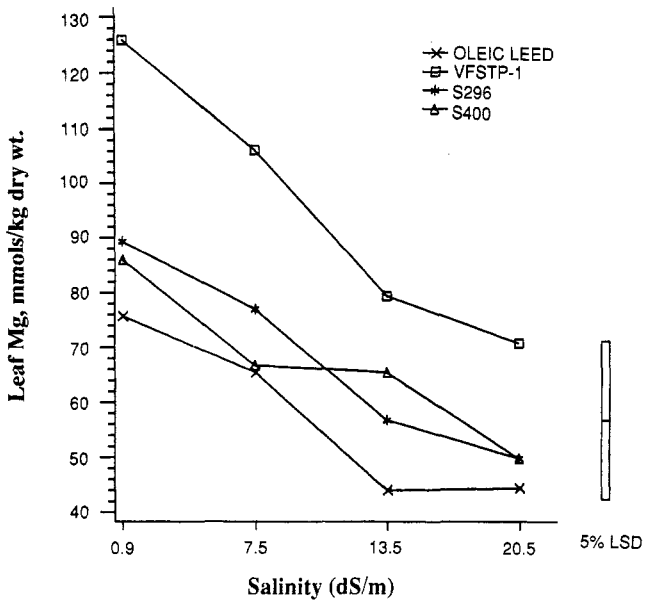

Figure 2. Leaf magnesium content for each variety.

with increasing salinity, as indicated by earlier maturity dates of salt-stressed plants. Devi et al. (1980) and Ahmed et al. (1977) also showed increased maturation rates in safflower as well as an increase in photosynthetic rates in salinity-treated plants. Earlier maturation of salt-stressed plants may account for the reduced number and weight of tertiary heads.

Yield increased in most instances under low-salt treatment as compared with the control. Rai (1977) reported increased yield with increasing salinity of the saturated-soil extract (EC_e) between 2 and 16 dS/m. Francois and Bernstein (1964) also noted an increased yield in the low-salt treatment (EC_e = 4.7 dS/m) over the control in two cultivars.

Leaf concentrations of Cl, Ca, and Na increased, whereas K and Mg decreased with increasing soil salinity as was found by Francois and Bernstein (1964). Kurian and Iyengar (1972) also reported an increase in minerals when plants were irrigated with sea water. When diluted sea water was amended with Hoagland's solution, N, K, and Ca increased regardless of salinity levels; however, Mg was not affected (Kurian and Iyengar, 1972).

Salinity stress had been previously shown to reduce oil content of safflower without affecting fatty acid composition of high-linoleate cultivars of safflower (Yermanos et al., 1964). Our results similarly show that as oil content was reduced with increasing salinity, no changes occurred in fatty acid composition of the three high-linoleate safflower cultivars. Fatty acid composition of the oil of the high-oleate cultivar was significantly changed, resulting in higher linoleate values with increasing salinity. This effect is similar to the sunflower chilling stress; i.e., low temperatures resulted in increased linoleate values (Knowles, 1972).

Safflower oil has been shown to be more stable to temperature stress during the growing season (Knowles, 1972) than sunflower oil. Fatty acid composition of sunflower oil changes dramatically depending on climate (Robertson et al., 1979; Nagao and Yamazaki, 1984). A complete reversal of the ratio of oleate to linoleate can take place. When sunflower is grown under high temperatures, oil lower in linoleate (21.7%) is produced whereas lower temperatures result in oil higher in linoleate (76.7%) (Nagao and Yamazaki, 1984). The same shift was observed in safflower although the magnitude of the shift was reduced from 75.5% linoleate at high temperatures to 82.2% at low temperatures (Knowles, 1972). Thus, low-temperature stress and high salinity resulted in increased linoleate values in safflower.

Salinity decreased plant height and seed yield in all four safflower cultivars examined. Oleic Leed was more sensitive to salt stress on a yield per plant basis (Table III) and on the basis of tertiary head yield per plot (Table II). This sensitivity to salt was accompanied by about a 10% shift in fatty acid composition from oleate to linoleate. The other cultivars, which were higher in lineolate than oleate, did not show significant shifts in fatty acid composition. Kuiper (1968) reported a correlation between salt sensitivity in grape and relatively higher amounts of unsaturated fatty acids in grape roots. Furthermore, salt-induced changes in plasma membrane lipid composition have been correlated with salt tolerance in different plant species (Erdei et al., 1980) and varieties (Stuiver et al., 1981). Since we did not examine differences in fatty acids in other safflower tissues, correlation with salt tolerance can only be surmised.

ACKNOWLEDGMENT

We thank Gary McDonald and Geraldine Secor for the mineral analyses, Richard Knowles and John H. Draper for technical assistance, and Robert Becker for supplying gas chromatography expertise and equipment.

Registry No. Mg, 7439-95-4; Cl^-, 16887-00-6; Ca, 7440-70-2; Na, 7440-23-5; P, 7723-14-0; linoleic acid, 60-33-3; oleic acid, 112-80-1; stearic acid, 57-11-4; palmitic acid, 57-10-3.

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Received for review November 24, 1986. Accepted August 24, 1987. Reference to a company and/or product named by the Department is only for purposes of information and does not imply approval or recommendation of the product to the exclusion of others that may also be suitable.

Total Gossypol Content of Glandless Cottonseed

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This paper reports the presence of total gossypol (TG) in gland-free cottonseed kernels. Thinly sliced kernels were examined with a microscope to assure complete absence of glands and analyzed by a modification of the official AOCS method, which can detect less than 1 ppm TG. Although sound, gland-free kernels from five varieties contained much less than 1 ppm of TG, those from each of nine varieties averaged 2-7 ppm TG, with over 10 ppm in one sample. All varieties meet the National Cottonseed Products Association's standard for Grade AAA seed (i.e., not to exceed 10 ppm TG) if glanded seeds are rigorously excluded. On the basis of a 1.25-g sample of cottonseed, 10 glands would contribute about 1 ppm of TG. Moldy and discolored kernels, in which no glands were visible, contained more TG than normal kernels.

Cottonseed is a plant protein product that can be used in foods to improve nutritional and functional properties (Lusas and Jividen, 1987). However, traditional varieties contain about 1% gossypol, a sesquiterpenoid phenolic aldehyde, and related compounds (Boatner, 1948). These compounds are toxic to monogastric animals (Berardi and Goldblatt, 1969), which restricts the use of cottonseed in feeds and foods. They can be deactivated (bound) by condensation with amino groups in the seed, but this reduces available lysine and the bound gossypol causes discoloration in foods (Blouin et al., 1981). Free and bound aldehydes are determined as a group by Method Ba 8-78 of the American Oil Chemists' Society (1979) and reported as total gossypol (TG).

Kernels of traditional (glanded) varieties of cottonseed contain intercellular structures, called pigment glands or simply glands, which are deposition sites for gossypol and related pigments. In fully glanded seed, these amber to dark red glands, which are 100-400 μm in diameter, are distributed throughout the cotyledons and periphery of the axis (Boatner, 1948) and are clearly visible against the light background color of the seed. Since the pioneering work of McMichael (1960), cottonseed varieties that do not contain glands, along with some that are partially glanded, have been developed by breeders throughout the cotton belt. Recently, Lusas and Jividen (1987) published a review, with extensive references, covering the development of glandless cottonseed and its use in foods.

Three grades for glandless cottonseed, based on maximum TG allowed, have been established by the National Cottonseed Products Association (1985), which regulates sale of cottonseed. It has been assumed that glandless cottonseed will not contain any TG; therefore, if TG is found in any sample labeled glandless, it must be contaminated with glanded seed (Phelps, 1977). However, during development of a method for determination of TG at parts per million levels (Fisher et al., 1987) we found TG in samples of glandless cottonseed that had been carefully inspected for presence of glands. This paper presents data on TG content per gland and number of glands per partially glanded kernel, which are needed to assess the possibility that the TG found in these samples came from contamination with partially glanded kernels. Results of TG analyses of kernels from 15 varieties of cottonseed, 1-3 varieties from each of 9 sources scattered from Mississippi to California, which confirm the presence of TG in some gland-free kernels, are also reported.

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