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The Determination of Oil Content and Fatty Acid Compositions of Domestic and Exotic Safflower (*Carthamus tinctorius* L.) Genotypes and Their Interactions

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Abstract: This study was carried out to determination of the differences and interactions between oil content and fatty acid of safflower cultivars. The experiments were arranged in randomized blocks experiment design with three replications in Van, Turkey. Three domestic (cvs of Yenice, Dinçer and Remzibey) and eight exotic cultivars (Centennial, GW9003, GW9005, GW9022, GW9023, Montola 2000, Montola 2001 and C9305) were grown in Van in 2000 and 2001. The results of variance analysis showed that the differences of oil content and fatty acid of cultivars were significant. The highest oil content was obtained from cvs. Montola 2001 and Montola 2000 (35.3 and 35.2%, respectively), while the lowest oil content was obtained from cv. Centennial (29.0%). In addition to, safflower cultivars were determined about 4.1 to 7.9%, palmitic acid, 1.1 to 4.6% stearic acid, 0.0 to 0.4% arachidic acid, 0.0 to 0.3% palmitoleic acid, 15.6 to 81.4% oleic acid, 7.2 to 77.3% linoleic acid and 0.1 to 1.2 % linolenic acid. The oil stability (18:1/18:2) of varieties ranged 0.20-0.30 in linoleic cultivars, 5.34-11.3 in oleic cultivars. On the other hand, positive and significant relationships were determined between oleic acid and palmitic acid (r = 0.317**), oil stability (r = 0.920**), while the greatest negative and significant relationship was found between oleic acid and linoleic acid (r = -0.999**).

Key words: Safflower, oil content, fatty acid, oil stability, interactions

INTRODUCTION

Safflower oil has been long used for industrial purposes, too, notably for preparing varnish, due to the high linoleic acid content of high linoleic varieties (Corleto *et al*., 1997). The seeds of the plant had a fat percentage of 25-37 % in old types; but in new types, this ratio has increased to 46-47% because the shell ratio was decreased and fat ratio was increased (Nagaraj, 1993). The cultivars with high linoleic acid can be used as health-care oil for making medicine for decreasing the cholesterol in order to help prevent atherosclerosis and heart disease. The oil of cultivars with high oleic acid can be used for frying as it tolerates high temperature (Guangwei and Dajue, 1999).

Safflower is one of the best examples of crops with variability for fatty acid composition in seed oil (Knowles, 1989). Fatty acid composition is known to be affected by environmental factors, soil characteristics (Donway and Rakow, 1987), seed, head, variety and cultural applications (Nagaraj, 1993). One of the major advantages of safflower is its diversity in seed oil quality types, with contrasting fatty acid profiles ranging from about 90% linolenic acid to 90% oleic acid (Velasco *et al*., 2005). Standart safflower oil contains about 6 to 8% palmitic acid, 2 to 3% stearic acid, 16 to 20% oleic acid and 71 to 75% linoleic acid (Velasco and Fernandez, 2001).

Very high levels of linoleic acid (87-89%) and very low oleic (3-7%) acid levels were found in an introduction from Portugal (Futehally and Knowles, 1981). Additionally, sources of variation for very higher oleic acid content (>85%) have been reported (Fernandez *et al*., 1993; Dajue *et al*., 1993). During seed development linoleic acid predominated in every lipid class while linolenic acid decreased with increasing maturation and was absent in fully mature safflower seeds (Nagaraj, 1993).

The fatty acid composition of vegetable oil determines its best commercial uses (Isigigur *et al*., 1995). High-oleic safflower oil is higher in monounsaturated than olive oil and is as low in saturated fats canola oil (Bergman, 1997). High-oleic safflower oil, because of its great stability and bland flavor, makes great frying oil (Smith, 1993). High-oleic safflower oil also has no linolenic fatty acid which is readily oxidized in oils such as soybean and canola to cause rancidity and off-flavors during storage or frying (Bergman, 1997). High-linoleic safflower oil, in view of its reported role in reducing blood cholesterol levels, it is now-a-days being utilized as premium edible oil (Nagaraj, 1993).

In the near future as oil resources increasingly deplete, safflower oil, like other vegetable oil substances, could be used on a large scale to produce both biofuel to be used for energy purposes in agriculture and alcohol for the production of surfactants (Corleto *et al*., 1997). Future

safflower will be hybrids, day-length neutral and spineless with seeds consisting of about 20% hull and 55% oil. Safflower oil will be close to zero saturated fatty acid and 85% oleic acid (Rubis, 2001).

The objective of this research was to determine the oil and fatty acid contents of domestic and exotic some safflower genotypes and their interactions under the Van ecological conditions.

MATERIALS AND METHODS

The study was conducted under irrigation conditions between 2000 and 2001 years on the experimental area of the Department of Field Crops, Agriculture Faculty, Yuzuncu Yil University in Van, Turkey. The soil of the experimental area was clay-loam, pH was 7.7, low in organic cmatter (1.0%), poor in available nitrogen (0.080 mg L^{-1}) and phosphorus content (27.5 kg ha^{-1}), rich in potassium and lime contents (524 kg ha^{-1} and 12%, respectively) and at least in salt content (0.080%). The total rainfall was 234.60 and 355.20 mm in the experimental years, compared with the long-term (1965-1995) mean of 412.5 mm. The monthly average temperature (first year 10.3°C and second year 10.9°C) and relative humidity (first year 59.4% and second year 60.1%) means were similar to the long-term average (8.3°C; 65.1%). The soil texture was clay-loam and its pH was 7.7. The soil texture was low in organic matter, nitrogen content, potassium and lime content. Phosphorus content was in middle level.

Three domestic (cvs. Yenice, Dinçer and Remzibey) and eight exotic cultivars (Centennial, GW-9003, GW-9005, GW-9022, GW-9023, Montola 2000, Montola 2001 and C-9305) were used as seed. Eleven safflower cultivars were sown in a randomized complete block design with three replications. The plot size for each treatment during 2000 and 2001 was 11.25 m^{-2} (5.0×2.25 m) and sown with 45×15 cm row spacing in the middle of May in the experiment years. Nitrogenous fertilizer (ammonium sulfate 21% and 150 kg ha^{-1}) and phosphorus fertilizer (triple super phosphate 42% and 100 kg ha^{-1}) were applied before sowing and all standard agronomic practices were applied.

Samples were obtained in the second week of October during both the years. Oil content of the samples was obtained using the soxhlet extraction method with hexane as described in AOAC -1990 (Anonymous, 1990). Totally 33 samples for eleven varieties were analyzed in terms of oil content and fatty acid composition (palmitic, stearic, arachidic, palmitoleic, oleic, linoleic and linolenic). The extracted oils were kept at -30°C until analyzed. The fatty acid methyl esters of total lipids were obtained by direct transmethylation AOCS- 1990. A mix of fatty acid methyl esters was supplied from Supelco (Bellefonte, PA); all chemicals were reagent grade. Thus, the fatty acids were converted into their methyl esters according to AOCS official Method Ce 2-66 AOCS-1990. And, the fatty acids were determined by using Thermo Quest 2000 gas chromatograph [Shimadzu Co. (Kyoto, Japan)] equipped with a flame ionization detector. Analyses were performed with DB-23; length 30 m, inner diameter 0.25 mm, film thickness 0.25 μm, capillary column. The temperatures of injection and detector were 240°C and column temperature was 195°C. The split ratio was 1: 80 and the carrier gas was nitrogen. The flow rates of nitrogen, hydrogen and dry air were 1, 35 and 350 mL min^{-1}, respectively.

The collected data were analyzed according to the randomized complete block design over years and in order to determine the relationships between oil content and fatty acids, correlation coefficients were calculated through computer TARIST statistical package.

RESULTS AND DISCUSSION

The results of analysis for oil content and fatty acids are showed in Table 1. The oil content and fatty acids composition of the examined safflower cultivars differed from each other.

Safflower varieties showed statistical differences on the basis of oil content ($p<0.01$). The lowest oil ratio of 29.0% was obtained from cv. Centennial. On the other hand, the highest oil content was obtained from cvs. Montola 2001 and Montola 2000 (35.3 and 35.2%, respectively). The oil contents of the other cultivars were ranged among these values (Table 1). Thin hulled varieties of safflower have higher oil (46%) and protein (Nagaraj, 1993). In addition to, Dajue *et al.* (1993) reported that the hull content is an important factor affecting the oil content, the lower the hull content is, the higher is the oil content. Bergman (1997) observed higher oil seed ratio of 41.3 to 43.1% in safflower. Bayraktar and Ülker (1992) recorded oil ratio among four safflower cultivars which ranged from 34.55 to 38.99%. Xuehai and Qingwei (1993) reported that the oil content of safflower is 30% or more. Geçgel *et al.* (2005) also reported that the oil content among 30.7 to 35.0% in Tekirdag and Edirne conditions. Çamaş *et al.* (2005) stated that the oil content of safflower cultivars varied between 24.5 to 27.2%. Knowles (1969) reported the variation in chemical composition of different safflower genotypes having different combinations of genes namely th and stp. Various factors affect oil content of safflower (Dajue *et al.*, 1993). Douglas *et al.* (2004) reported that 33% of the variation in seed oil content was

Table 1: The oil content and fatty acid composition of safflower cultivars*

Cultivars	Oil cont. (%)	C 16:0 Palmitic	C 18:0 Stearic	C 20:0 Arachidic	C 16:1 Palmitoleic	C 18:1 Oleic	C 18:2 Linoleic	C 18:3 Linolenic	Oil stability (18:1/18: 2)
Centennial	29.0e	4.1g	2.7f	0.4a	0.3a	17.7g	74.4c	0.9b	0.24
GW-9003	34.0ab	4.7f	1.8h	0.2c	0.3a	15.7h	77.3a	0.9b	0.20
GW-9005	33.8ab	5.5d	2.9de	0.3b	0.3a	15.6h	75.5b	0.8bc	0.21
GW-9022	30.5de	4.7f	2.5g	0.1d	0.1b	78.0c	14.0f	0.4de	5.57
GW-9023	32.2bcd	4.8f	4.6a	0.3b	0.3a	75.8d	14.2f	0.6c	5.34
Montola-2000	35.2a	7.9a	3.1d	-	0.2b	81.4a	7.2h	0.1f	11.03
Montola-2001	35.3a	5.8bc	1.5i	-	0.2b	79.7b	12.8g	0.2f	6.20
C-9305	32.8abc	6.0b	1.1j	0.3b	-	19.7f	71.9d	1.2a	0.27
Dinçer	30.6cde	5.7cd	3.9b	0.1d	-	20.9e	69.0e	0.9b	0.30
Yenice	31.3cde	5.6cd	2.8ef	0.1d	-	15.9h	75.4b	0.2ef	0.21
Remzibey	31.4cde	5.0e	3.3c	0.1d	0.1b	18.4g	72.5d	0.5d	0.25
LSD	2.38**	0.241**	0.213**	0.04 **	0.096**	0.257**	00.927**	0.163**	

*Means within a column with different letter (s) are different at p<0.01 using the LSD; ** Highly significant

Table 2: Correlation coefficients between the oil content and fatty acids of safflower seed*

Traits	Oil content	Palmitic	Stearic	Arachidic	Palmitoleic	Oleic	Linoleic	Linolenic	(Oil stability)
Oil content	1.000	0.281*	-0.248*	-0.269*	0.076ns	0.217ns	-0.215ns	-0.183ns	0.307**
Palmitic		1.000	-0.071ns	-0.308**	-0.333**	0.317**	-0.339**	-0.363**	0.562**
Stearic			1.000	-0.008	0.157ns	0.116ns	-0.142ns	-0.106ns	0.094ns
Arachidic				1.000	0.219ns	-0.330**	0.333**	0.319**	-0.302**
Palmitoleic					1.000	0.047ns	-0.042ns	0.145ns	0.048ns
Oleic						1.000	-0.999**	-0.582**	0.920**
Linoleic							1.000	0.585**	-0.927**
Linolenic								1.000	-0.629**
(Ol / Li)									1.000

ns: Not significant, * Significant at alpha level 5%, ** Significant at alpha level 1%

a consequence of environmental and technical variation; thus 67% of the variation observed was due to genetic factors. The results of the present study indicated are lower than Bergman (1997) and Bayraktar and Ülker (1992), but it's higher than Çamaş *et al.* (2005). Present findings are agreement results of Geçgel *et al.* (2005) and Xuehai and Qingwei (1993).

Palmitic, stearic, arachidic, palmitoleic, oleic, linoleic and linolenic acids were the principal fatty acids for all safflower samples analyzed. Significant differences existed in the fatty acid compositions of the safflower varieties (Table 1).

Oleic acid content ranged from 15.6 to 81.4%, the highest oleic acid determined in cv. Montola 2000 (81.4%), followed by Montola 2001 (79.7%) and GW-9022 (78.0). On the other hand, the highest values for linoleic acid content were recorded in GW-9003 (77.3%). It is ranged from 7.2 to 75.5% for the other cultivars (Table 1). High oleic types have higher levels of oleic acid than Standard types which are richer in linoleic acid. Velasco and Fernandez (2001) reported that the safflower showed a great variability for seed oil fatty acids, with an average composition of 26.2% oleic (from 5.6 to 86.9%) and 65.9% linoleic acid (from 7.1 to 88.7%). Daju *et al.* (1993) also reported that the fatty acids were determined for 2100 accessions of safflower and their ranges are: Linoleic acid 11.13-85.60%, oleic acid 6.74-81.84%. Dajue and Griffee (2001) indicated that the cv GW-9024 possessed the highest oleic acid (59.0%) and cv KU-4038 has the highest content of linoleic acid (79.0%). The contents of the fatty acid and linoleic acid in safflower oil have a negative correlation with that of linoleic acid (Zongwen and Yuehua, 2005). Geçgel *et al.* (2007) reported that the lowest content of oleic acid was found in the highest linoleic acid content. Similar results were also obtained in present research.

The highest values for the stearic acid content were determined as 4.6% in cv. GW-9023. Stearic acid content of the other cultivars varies 1.6 to 3.8%. It is the lowest one in the four main fatty acids. The average content differs from country to country (Jianguo *et al.*, 1993). Geçgel *et al.* (2007) reported that the stearic acid content decreased in spring sowing and the stearic content were higher in the centennial variety than in the Montola 2001 variety. Velasco and Fernandez (2001) also reported that the safflower showed a great variability for seed oil fatty acids, with an average composition of 2.2% stearic acid (from 0.8 to 9.9%). Daju *et al.* (1993) reported that stearic acid range is 0.01-4.88%. Present results are consistent with these findings.

Palmitic acid content ranged between 4.1 to 7.9%, Montola 2000 exhibited higher mean than the other cultivars. Palmitic acid was the main saturated fatty acid followed by stearic acid. Daju *et al.* (1993) reported that palmitic acid range is 2.10-29.03%. Among the saturated fatty acids, palmitic acid significantly varied from 7.4 to

17.3 in wild spices and in cultivated species, it ranged from 6.3-7.5% (Muralidharudu *et al*., 1993). Velasco and Fernandez (2001) also reported that the safflower showed a great variability for seed oil fatty acids, with an average composition of 5.8% palmitic (from 3.4 to 10.2%). Geçgel *et al*. (2007) found this value to be 7.4 to 6.0% in montola 2001 and 10.6 to 7.2% in centennial. These researchers that stated the palmitic acid percentage in relative amount decreased during seed development. These results were in accordance with the results of our study. Similar results were reported by Bergman *et al*. (2001) and Penumetcha *et al*. (2000)

Differences of arachidic, palmitoleic and linolenic acids were significant. But, they are much lower. Some even lack arachidic and palmitoleic acids. The average ratios for both acids were 0.15% except linolenic (0.61%). Downey and Rakow (1987) reported that it is possible to raise the level of the polyunsaturated fatty acid linoleic and at the same time reduce the linolenic values. On the other hand, it was reported that increase in climate temperatures resulted in a decrease for the synthesis of linoleic and linolenic acids and increase in synthesis of oleic acid (Pleines and Freidt, 1988). Geçgel *et al*. (2007) reported that linolenic content was present in less than 0.3% and it was not found is some samples analyzed during seed development. Hill and Knowles (1968) reported that the linolenic acid was not found past 10 days after flowering in any variety. Nagaraj (1993) determined that arachidic acid range is 1.2 to 3.6%. Present results for linolenic acid are high than Geçgel *et al*. (2007), but also for arachidic acid are low than Nagaraj (1993).

The oil stability (18:1/18:2) of cultivars ranged 0.20 to 0.30 in linoleic cultivars, 5.34 to 11.3 in oleic cultivars. Muralidharudu *et al*. (1993) reported that the stability index of wild species on an average was higher (0.26) compared to cultivated varieties (0.16). Oxidative stability of the oil was inversely related to linoleic acid and, high oleic types had better oil stability (Knowles, 1989; Purdy, 1985). The results of the present study indicated are high oil stability values in cvs, Montola 2000, Montola 2001, GW-9022 and GW-9023 that were high in oleic acid content in theirs fatty acid compositions.

The results of simple correlation coefficients of analyses for the traits investigated are showed in Table 2. Positive significant relationships were found between oil content and palmitic acid (r = 0.281*), oil stability (r = 0.307**). Möllers and Schierholt (2002) indicated that positive reletions between oil content and oleic acid. On the other hand, significant negative correlations were determined between oil content and stearic acid (r = -0.248*), arachidic acid (r = -0.269*).

The fatty acid content varies very much with geographical origin of accessions/varieties (Dajue *et al*. 1993). Zongwen and Yuehua, 2005 reported that oil content in safflowrer seed was negative correlation between the palmitic acid and stearic acid. Present results confirm the findings of Möllers and Schierholt (2002) and Zongwen and Yuehua (2005) for stearic acid.

The significant positive correlations were determined between oleic acid and oil stability (r = 0.920**); linoleic acid and linolenic acid (r = 0.585**); palmitic acid and oil stability (r = 0.562**); arachidic acid and linoleic acid (r = 0.333**); arachidic acid and linolenic acid (r = 0.319**); palmitic acid and oleic acid (r = 0.317**). On the contrary, the significant negative correlations were fined between oleic acid and linoleic acid (r = -0.999**); linoleic acid and oil stability (r =- 0.927**); linolenic acid and oil stability (r = -0.629**; oleic acid and linolenic acid (r = -0.582**); palmitic acid and linolenic acid (r = -0.363**); palmitic acid and linoleic acid (r = -0.339**); palmitic acid and palmitoleic acid (r = -0.333**); arachidic acid and oleic acid (r = -0.330**); palmitic acid and arachidic acid (r = -0.308*) arachidic acid and oil stability (r = - 0.302**).

The gene present in most safflower varieties Ol, produces oil with high levels of linoleic acid and low levels of oleic acid while the gene ol gives an oil low in linoleic acid and high in oleic acid. The third gene ol[1] produces oil with equal levels of 18:1 and 18:2 (Nagaraj, 1993). Cultivars with very high levels of linoleic or oleic acid would increase the value of oils (Knowles, 1989). But, there was a inverse relationship between oleic acid and linoleic acid (Jianguo *et al*., 1993; Geçgel *et al*., 2007; Nagaraj, 1993). During seed development linoleic acid predominated in every lipid class while linolenic acid decreased with increasing maturation and was absent in fully mature safflower seeds (Nagaraj, 1993). In addition to, Daju *et al*. (1993) reported that linoleic aid is negatively correlated with all the other component and such negative correlation is greatest with oleic acid (r = -0.9502) followed by that of palmitic acid (r = -0.3247) and also oleic acid or palmitic acid have very little correlation with stearic acid. These results are in agreement with present findings.

The nutritional quality indices of the oil were generally low due to lower levels of linoleic acid and higher levels of oleic acid. Varieties with higher oleic acid and lower linoleic acid would be more preferred for achieving better stability (Muralidharudu *et al*., 1993). The oxidative stability of oils is linked closely with fatty acid composition. In fatty acid composition, oxidative stability decreases as the content of unsaturated fatty acid increases. So the reason for high rancimat values in Montola 2001 that was high in oleic acid content in its

fatty acid composition Geçgel *et al.* (2007). Bratcher and Kemmerer (1969) reported higher induction periods in safflower oils with higher oleic acid content than those with high linoleic acid content. Möllers and Schierholt (2002) indicated that the high oleic acid mutation has a pleiotropic effect on palmitic acid and oil content. They also reported that results indicated that palmitic acid content can be reduced either by recurrent selection for increased oleic acid content or continued selection for high oil content.

As a result, eleven safflower varieties have shown difference in the oil content and fatty acid composition in Van ecological conditions. Varieties such as Montola 2000, Montola 2001, GW-9022 and GW-9023", which have strong oil stability. Therefore, the improvement programmers for exotic cultivars could be planned using these varieties with high oil content and high oil quality. For this reason, cultivars such as Montola 2000 and Montola 2001 could be considered.

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