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Variation in oil content and fatty acid composition of sesame accessions from different origins

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SUMMARY: Oil content and fatty acid composition are very important parameters for the human consumption of oilseed crops. Twenty-four sesame accessions including seven collected from various geographical regions of Turkey and 11 from different countries were investigated under field conditions for two consecutive years (2015 and 2016). The sesame accessions varied widely in their oil content and fatty acid compositions. The oil content varied between 44.6 and 53.1% with an average value of 48.15%. The content of oleic acids, linoleic acid, linolenic acid, palmitic acid,and stearic acid varied between 36.13–43.63%, 39.13–46.38%, 0.28–0.4%, 8.19–10.26%, and 4.63–6.35%, respectively. When total oil content and fatty acid composition were compared, Turkish sesame showed wide variation in oil and fatty acid compositions compared to those from other countries. However, the accessions from other countries were fewer compared to those from Turkey. It is essential to compare oil and fatty acid composition using a large number of germ plasm from different origins. In sesame oil, the average contents of oleic acid and linoleic acid were 39.02% and 43.64%, respectively, and their combined average content was 82.66%, representing the major fatty acid components in the oil from the sesame accessions used in the present study. The results obtained in this study provide useful information for the identification of better parents with high linoleic and oleic acid contents for developing elite sesame varieties with traits which are beneficial to consumer health.

KEYWORDS: *Fatty Acid; LDR; Linoleic Acid; ODR; Oil Content; Sesame*

RESUMEN: ***Variación en el contenido de aceite y composición de ácidos grasos de accesiones de sésamo de diferentes orígenes.*** El contenido de aceite y la composición de ácidos grasos de cultivos oleaginosos son parámetros muy importantes para el consumo humano. Veinticuatro accesiones de sésamo, incluidas siete recolectadas en diversas regiones geográficas de Turquía y once en otros países diferentes, se investigaron en condiciones de campo durante dos años consecutivos (2015 y 2016). Las accesiones de sésamo variaron ampliamente en su contenido de aceite y composiciones de ácidos grasos. El contenido de aceite varió entre 44,6 y 53,1% con un valor promedio de 48,15%. El contenido de ácido oleico, linoleico, linolénico, palmítico y esteárico variaron entre 36,13-43,63%, 39,13-46,38%, 0,28-0,4%, 8.19-10.26% y 4,63-6,35% respectivamente. Cuando se compararon el contenido total de aceite y la composición de ácidos grasos el ajonjolí turco mostró una amplia variación en la composición del aceite y los ácidos grasos en comparación con los de otros países. Sin embargo, las adhesiones de otros países fueron menores en comparación con las de Turquía. Es esencial comparar la composición del aceite y de los ácidos grasos usando gran cantidad de germoplasma de diferentes orígenes. En aceites de sésamo, el contenido promedio de ácido oleico y ácido linoleico fue 39,02% y 43,64%, respectivamente, y su contenido promedio combinado fue de 82,66% que son los ácidos grasos mayoritarios en los aceites de las accesiones de sésamo usadas en este estudio. Los resultados obtenidos proporcionan información útil para la identificación de mejores orígenes con alto contenido de ácido linoleico y oleico, para el desarrollo de variedades de sésamo de élite con características beneficiosas para la salud del consumidor.

PALABRAS CLAVE: *Ácido graso; Ácido linoleico; Contenido de aceite; LDR; ODR; Sésamo*

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1. INTRODUCTION

Sesame (*Sesamum indicum* L. - Pedaliaceae) is one of the oldest and most important oil seed crops known to mankind. Sesame was initially grown during the ancient Harappan, Mesopotamian, and Anatolian eras for its edible seed and oil (Bedigian, 2004) and is now grown in more than 60 countries. The origin of sesame (*Sesamum indicum* L.) continues to be debated, but evidence has shown that sesame originated in South Africa and India (Bedigian, 2004; Kobayashi, 1986; Yol and Uzun, 2012). In both circumstances, Turkey played a key role in the distribution of sesame (Uzun *et al*., 2008) since it was at a major crossroad of trade between the East and West in ancient times. Although there is a wide range of varieties and ecotypes of sesame adapted to various ecological conditions in Turkey, the cultivation of modern varieties is very limited owing to the lack of genetic information, especially about seed quality parameters.

Sesame seeds are used in bread, cakes, crackers and especially simit (ring-shaped bread) in commercial bakeries in Turkey. The seed is also made into tahin (sesame butter) and halva. In addition, it has been used in industries such as paint, pharmaceuticals, cosmetics, perfumery, insecticides and soap. Sesame seeds contain oil (50%), protein (24%) and micro elements (Fe, Zn, Ca, Mg, Cu etc.). Compared to other oilseed crops, sesame yields superior oil quality and quantity, with its average oil content constituting approximately 50% of seed weight (Ashri, 1989). The sesame seed is commonly known as the 'Queen of oil seeds', probably due to its high nutritional and therapeutic value, and resistance to oxidation and rancidity (Johnson *et al*., 1979; Sukumar *et al*., 2008). In addition, sesame seeds contain a group of compounds called lignans, including sesamol, sesamolin, and sesamin, all known to have health benefits on account of their anti-tumorigenic, estrogenic and/or anti-estrogenic, hypocholesterolemic, antioxidant and hypoglycemic properties, along with their positive effect on sperm quality (Suja *et al.*, 2005; Shittu *et al*., 2007; Shittu *et al*., 2008). Sesame ingestion (50 g sesame seed powder daily for 5 weeks) positively affected sex hormones, antioxidant status, and blood lipids in postmenopausal woman (Wu *et al*., 2006). The seed powder is useful in amenorrhea, dysmenorrhea, ulcers, and bleeding haemorrhoids (Kapoor 2001; Chandel *et al*., 1996).

In sesame oil, oleic and linoleic acids are the predominant fatty acids and constitute more than 80% of the total fatty acid content. The high level of monounsaturated and polyunsaturated fatty acids (PUFAs) increases the quality of the oil for human consumption (Mondal *et al*., 2010). Furthermore, the high levels of oleic acid and linoleic acid, PUFA, reduce blood cholesterol and the risk of cardiovascular diseases, and also play an important role in preventing atherosclerosis (Ghafoorunissa, 1994; Teres *et al*., 2008).

Sesame has been under cultivation in Asia for over 5,000 years and in Anatolia for over 1,000 years. There are numerous sesame populations adapted to different environments in this part of the world. These landraces are an important source of genetic variation for breeders. Information about genetic diversity is crucial in plant breeding programs because crosses between parents with high inter-parental diversity may help to develop varieties with a broad genetic base (Sing, 1990; Keneni *et al*., 2005). Insufficient genetic information about Turkish sesame populations is the main factor influencing the development of elite varieties (Baydar *et al*., 1999).

Although sesame is one of the most important oil crops in Turkey, very limited genetic and breeding studies have been conducted. Only 13 sesame cultivars have been registered in Turkey, despite good genetic variation and all of them being obtained via selection from breeding programs. Therefore, furhter genetic studies and determination of agro-morphologic and quality parameters of sesame populations in Turkey are required. Moreover, Turkey is a major importer of sesame seeds. For this reason, the characterization of valuable Anatolian sesame genetic resources is essential for the successful breeding of sesame with superior oil properties in Turkey.

The purpose of this study was to evaluate the variability in oil content and fatty acid composition among 24 sesame accessions from Turkey and 11 different countries. The study was performed over a period of two years. The information obtained will be useful to sesame breeders for planning efficient breeding strategies for new and improved varieties.

2. MATERIALS AND METHODS

2.1. Plant material

Twenty-four different sesame accessions (belonging to Turkey and 11 other countries) were used as plant material in this study (Table 1). The sesame accessions were procured from the Aegean Agricultural Research Institute (Kahramanmaras, Balikesir-Kepsut, Mugla-Koycegiz, Kilis, Bursa-Orhangazi, Malatya-Ispendere, Orhangazi-99), United States Department of Agriculture (India, Afghanistan, Libya, Greece1, Greece 2, Zaire, USA, Egypt1, Egypt 2, Ethiopia) and the other seven were personally collected by the author (Iran1, Iran 2, Iran 3, Iran 4, Iran 5 (Tabriz), Iraq (Karkuk), and Pakistan (Multan)). The field experiment was conducted at the Experimental Farm of Cukurova University (41°04´N, 36°71´E, and 36 m), in Adana

(Turkey) for two consecutive years in 2015 and 2016. In the Adana province, a typical Mediterranean climate prevails and the winters are warm and rainy whereas the summers are hot and dry. During the study period, monthly average day temperatures ranged from 25.0 °C to 30.0 °C in 2015 and 27.1 °C to 29.9 °C in 2016. The total rainfall was 146.1 mm and 93.8 mm during the growing periods in 2015 and 2016, respectively. The average relative humidity ranged from 63.4 to 69.8% in 2015 and 66.1 to 69.0% in 2016 (Table 2).

The experiments were conducted in a Randomized Complete Block design with three replications. Before planting, 200 $kg \cdot ha^{-1}$ of DAP (36 $kg \cdot ha^{-1}$ N, 92 $kg \cdot ha^{-1}$ P) fertilizers were applied. Ammonium nitrate (33%N) at the rate of 200 $kg \cdot ha^{-1}$ was applied once before the first irrigation. Twenty-four different sesame populations (belong to Turkey and different countries) were used as plant material in this study (Table 1). Sesame seeds were sown in the second week of June, 2015 and 2016. The accessions were grown in four row plots of 5 m row length with a row spacing of 70 cm and intra-row spacing of 15 cm. Thinning was carried out after 25 days of sowing to secure one plant per 15 cm. Sprinkler irrigation was established immediately after sowing and thereafter used when necessary based on soil and plant conditions. Weeding was carried out by hand and no herbicides were applied during the growing seasons. All the plants were harvested in the last week of September, in 2015 and 2016.

Table 1. The list of sesame accessions from different countries

Name of the germ plasm accession	Origin
Kahramanmaras (T)	India
Balikesir-Kepsut (T)	Afghanistan
Mugla-Koycegiz (T)	Libya
Kilis (T)	Greece1
Bursa-Orhangazi (T)	Greece 2
Malatya-Ispendere (T)	Zaire
Orhangazi-99 (T)©	Iraq
Iran1	USA
Iran2	Pakistan
Iran3	Egypt1
Iran4	Egypt 2
Iran5	Ethiopia

©: Cultivar; T: Turkey.

2.2. Oil extraction and GC analysis

The samples of 24 genotypes grown in 2015 and 2016 were subjected to oil extraction using a Soxhlet apparatus and a gravimetric method. The experiments were performed in a Randomized Complete Block design with three replicates and seeds were bulked (20 g from each replication) and 5 g clean and mature seed samples were taken for oil content and fatty acid analysis. The oil content was determined by comparing the weights of 5 g seed samples before and after extraction using a Soxhlet apparatus (FOSS) with petroleum ether for 3 h.

An oil sample of 500 mg was dissolved in 2 ml isooctane followed by 1.5 ml of 0.5 M methanolic NaOH. The tube was then vortexed and held in boiling water for 7 min and allowed to cool to room temperature. Two ml of BF3 (Boron trifluoride) were added, vortexed, and held in boiling water for 5 min and allowed to come down to room temperature. The tube was vortexed after adding 5 ml NaCl, centrifuge at 4,000 rpm for 10 min. The supernatant was used for GC analyses (AOAC 1984).

The fatty acid (FA) composition was analyzed using a GC Clarus 500 with auto sampler (Perkin Elmer, USA) equipped with a flame ionization detector and a fused silica capillary SGE column (30 m • 0.32 mm, ID • 0.25 lm, BP20 0.25 UM, USA). The oven temperature was brought to 140 °C for 5 min, then raised to 200 °C at a rate of 4 °C/min and to 220 °C at a rate of 1°C/min, while the injector and the detector temperatures were set at 220 °C and 280 °C, respectively. All analyses were performed in triplicate, and their means were reported. The data were statistically analyzed using a JUMP 8.1.0 statistical software package. The Least Significant Differences (LSD) test was used to compare the treatments at the 0.05 level.

Table 2. The average monthly temperature, monthly precipitation, and humidity during the 2015 and 2016 growing seasons in Adana-Turkey

	Average Temperature (°C)		Precipitation (mm)		Humidity (%)	
Months	2015	2016	2015	2016	2015	2016
June	25.0	27.1	4.8	45.6	69.6	66.1
July	28.4	29.5	0.4	0.2	69.8	67.5
August	30.0	29.9	10.9	8.2	63.4	69.0
September	28.4	26.3	130.0	39.8	64.8	61.8

2.3. Determination of fatty acid desaturation ratios

Within the desaturation pathway, the oleic desaturation ratio (ODR) and the linoleic desaturation ratio (LDR) (Pleines and Friedt, 1988) were used to determine the efficiency of the desaturation from OA to LA (ODR) and from LA to ALA (LDR). They were calculated as follows:

$$ODR = \frac{C18:2 + \%C18:3}{\%C18:1 + \%C18:2 + \%C18:3}$$

$$LDR = \frac{\%C18:3}{\%C18:2 + \%C18:3}$$

The data were statistically analyzed by One-Way ANOVA using the SPSS software.

3. RESULTS AND DISCUSSION

3.1. Oil content and fatty acid profile

The oil content and fatty acid composition in oilseed crops is affected by genotype, location, temperature, moisture content, growing conditions, planting date, fertilization, and the interaction these factors (Ul-Hassan and Ahmed, 2012).

A significant variation in oil content was found among the 24 sesame accessions as shown in Table 3. The oil content of the 24 sesame accessions varied between 42.8-54.37% over a two-year period, the average being 47.7%. The highest oil content was obtained from the Mugla-Koycegiz (T) Libya accession, whereas the lowest value was obtained from the Iran 1 accession. The range of oil content found was narrower than that in the Turkish (Uzun *et al*., 2008), worldwide (Yermanos *et al*., 1972), and

Table 3. Oil contents and fatty acid compositions of sesame germ plasm of different countries in 2015

	C16:0	C18:0	C18:1	C18:2	C18:3	C:20	OC
Kahramanmaras (T)	9.60	4.93	39.11	43.38	0.28	0.53	48.53
Balikesir-Kepsut (T)	9.65	5.06	39.60	42.76	0.31	0.55	49.50
Mugla-Koycegiz (T)	10.26	4.79	37.24	44.48	0.36	0.52	53.50
Kilis (T)	9.71	5.12	41.78	40.54	0.32	0.55	45.27
Bursa-Orhangazi (T)	10.01	5.29	39.63	42.10	0.34	0.55	47.30
Malatya-Ispendere(T)	9.91	5.31	39.46	42.50	0.29	0.54	45.57
Orhangazi-99 (T)©	9.32	5.12	39.48	43.47	0.30	0.54	47.00
India	9.43	4.98	41.27	40.93	0.29	0.55	43.93
Afghanistan	9.33	5.16	37.59	45.07	0.28	0.54	46.67
Libya	9.76	5.55	38.52	43.16	0.38	0.57	49.80
Greece 1	9.31	6.21	38.62	43.13	0.28	0.60	49.13
Greece 2	9.53	5.95	39.41	42.10	0.32	0.59	52.07
Egypt 1	8.96	4.97	37.48	45.80	0.40	0.53	51.53
Egypt 2	9.68	5.09	40.80	41.53	0.32	0.53	49.13
Ethiopia	10.09	5.15	38.22	43.55	0.34	0.54	49.50
Zaire	9.48	4.63	37.91	45.14	0.33	0.55	49.00
Iraq	8.85	5.03	43.09	40.39	0.30	0.57	45.70
USA	9.61	5.59	39.54	42.55	0.38	0.55	44.83
Iran 1	9.51	5.72	38.69	43.24	0.39	0.57	46.80
Iran 2	8.53	5.45	42.19	41.02	0.40	0.53	44.40
Iran 3	9.42	5.31	36.14	46.38	0.30	0.52	45.10
Iran 4	8.49	5.17	38.05	45.55	0.29	0.53	42.90
Iran 5	9.50	5.47	38.11	44.08	0.30	0.61	45.73
Pakistan	8.70	5.70	41.76	41.19	0.28	0.54	51.10
Mean	9.44	5.28	39.32	43.08	0.32	0.55	47.67
LSD (0.05)	0.358**	0.126**	0.125**	0.129**	0.031**	0.030**	1.235**
CV (%)	2.31	1.45	0.19	0.18	5.92	3.43	1.58

(T): Turkey; ©: Cultivar; OC: Oil Content; **: Significant at $p < 0.01$.
16:0: Palmitic acid; 18:0: Stearic acid; 18:1: Oleic acid; 18:2: Linoleic acid: 18:3: Linolenic acid; 20:0 Arachidic acid.

Mediterranean core collection (Yol *et al*., 2015). These differences may have originated due to different genetic backgrounds and growing conditions.

The fatty acid compositions of the 24 sesame accessions are shown in Tables 3-5. In sesame oil, oleic acid and linoleic acid are the major fatty acids which form more than 80% of the total oil content. These were found in large amounts in the oil of all sesame accessions. The data belonging to the oil content and fatty acid composition for 2015, 2016 and in a two-year average are presented in Tables 3–5. Statistically significant differences were observed among the accessions for oil content and fatty acid composition in 2015, 2016 and in a two-year average. The oil contents varied between 42.9-53.5% in 2015 and between 42.8-54.37% in 2016 (Tables 3-4). According to a two-year average, the highest oil content was recorded for the Greece 2 (53.12%) accession, while the lowest oil content was recorded for Iraq (44.63%).

The highest oleic (43.09%) and the lowest linoleic acid (40.39%) percentages were obtained from the Iraq accession for 2015 and the highest linoleic acid (46.38%) and the lowest oleic acid (36.14%) percentages were obtained from the Iran 3 accession in 2015 (Table 3). The Kilis (T) accession had the highest oleic (43.63%) and the lowest linoleic (39.13%) acid contents; while the Libya accession had the higest linoleic (46.13%) and the lowest oleic (36.65%) acid contents in 2016 (Table 4). The oleic acid contents varied between 36.14 and 43.63% with a mean value of 39.02% (Table 5). Linoleic acid in sesame seed oil ranged from 36.13 to 46.38% with an average value of 43.64%. The linoleic acid content was thus found to be higher than the oleic acid content in sesame seed oil. Oleic acid content percentages in earlier reports by Uzun *et al*., (2008) and Were *et al*., (2006) were lower than those in the present study, although they reported higher linoleic acid contents than that found in the present study.

Table 4. Oil content and fatty acid composition of sesame germplasm of different countries in 2016

	C16:0	C18:0	C18:1	C18:2	C18:3	C:20	OC
Kahramanmaras (T)	8.90	5.20	37.73	45.49	0.29	0.51	48.60
Balikesir-Kepsut (T)	9.45	5.14	39.45	43.10	0.30	0.54	43.30
Mugla-Koycegiz (T)	9.52	5.31	37.75	44.51	0.32	0.55	49.90
Kilis (T)	8.53	5.89	43.63	39.13	0.29	0.58	47.77
Bursa-Orhangazi (T)	9.02	5.52	40.93	41.51	0.31	0.55	51.40
Malatya-spendere(T)	9.19	5.13	36.57	46.21	0.29	0.58	48.37
Orhangazi-99 (T)©	9.09	5.26	38.63	44.31	0.30	0.54	48.60
India	9.22	4.97	39.68	43.38	0.30	0.54	53.87
Afghanistan	9.27	5.22	37.21	44.95	0.29	0.55	47.23
Libya	9.39	4.97	36.65	46.13	0.34	0.56	54.37
Greece 1	8.80	6.35	38.32	43.56	0.34	0.60	45.67
Greece 2	9.30	5.04	38.25	44.62	0.33	0.57	54.17
Egypt 1	8.78	4.86	37.63	45.68	0.39	0.51	52.33
Egypt 2	9.35	5.76	38.91	43.30	0.32	0.57	54.07
Ethiopia	9.46	4.90	37.89	45.04	0.32	0.55	49.37
Zaire	8.88	5.13	38.38	44.97	0.35	0.57	45.43
Iraq	8.67	5.45	40.39	42.72	0.29	0.56	43.57
USA	9.10	4.76	37.26	46.15	0.32	0.54	50.80
Iran 1	9.15	5.53	38.84	43.66	0.37	0.58	42.80
Iran 2	8.19	5.35	40.22	43.75	0.35	0.53	46.30
Iran 3	8.19	5.63	40.80	42.88	0.31	0.58	45.70
Iran 4	8.62	5.32	37.84	45.67	0.34	0.53	47.37
Iran 5	8.85	5.07	37.43	45.89	0.33	0.58	48.40
Pakistan	8.80	4.84	39.21	44.23	0.32	0.54	47.77
Mean	8.99	5.27	38.73	44.20	0.32	0.55	48.63
LSD (0.05)	0.159**	0.153**	0.148**	0.148**	0.022**	0.024**	1.184**
CV (%)	1.08	1.77	0.23	0.20	4.27	2.64	1.48

(T): Turkey; ©: Cultivar; OC: Oil Content; **: Significant at $p < 0.01$.
16:0: Palmitic acid; 18:0: Stearic acid; 18:1: Oleic acid; 18:2: Linoleic acid: 18:3: Linolenic acid; 20:0 Arachidic acid.

Table 5. Oil content and fatty acid composition of sesame germ plasm of different countries in a two-year average

	C16:0	C18:0	C18:1	C18:2	C18:3	C:20	OC
Kahramanmaras (T)	9.13	5.20	39.14	43.77	0.29	0.52	48.57
Balikesir-Kepsut (T)	9.45	5.09	39.16	43.43	0.31	0.55	46.40
Mugla-Koycegiz (T)	9.77	5.07	38.17	43.97	0.34	0.53	51.70
Kilis (T)	9.37	5.35	40.96	41.39	0.31	0.57	46.52
Bursa-Orhangazi (T)	9.38	5.44	41.09	41.15	0.32	0.55	49.35
Malatya-Ispendere (T)	9.54	5.28	38.77	43.50	0.29	0.56	46.97
Orhangazi-99 (T)©	9.32	5.20	38.71	44.04	0.30	0.54	47.80
India	9.28	5.05	40.00	42.73	0.30	0.55	48.90
Afghanistan	9.31	5.12	38.42	44.06	0.29	0.54	46.95
Libya	9.48	5.24	37.52	44.76	0.36	0.57	52.08
Greece 1	9.23	5.94	38.17	43.78	0.31	0.60	47.40
Greece 2	9.29	5.76	38.71	43.35	0.33	0.58	53.12
Egypt 1	9.05	5.11	37.98	44.95	0.39	0.52	51.93
Egypt 2	9.30	5.25	39.08	43.52	0.32	0.55	51.60
Ethiopia	9.69	5.16	38.65	43.67	0.33	0.55	49.43
Zaire	9.38	4.93	38.11	44.80	0.34	0.56	47.22
Iraq	8.90	5.12	40.54	42.72	0.30	0.57	44.63
USA	9.15	5.20	39.51	43.42	0.35	0.55	47.82
Iran 1	9.34	5.47	38.64	43.75	0.38	0.58	44.80
Iran 2	8.68	5.47	40.39	42.74	0.38	0.53	45.35
Iran 3	8.65	5.45	39.38	43.88	0.31	0.55	45.40
Iran 4	8.63	5.32	38.12	45.28	0.32	0.53	45.13
Iran 5	8.97	5.26	37.83	45.19	0.31	0.59	47.07
Pakistan	8.89	5.27	39.58	43.47	0.30	0.54	49.43
Mean	9.21	5.28	39.03	43.64	0.32	0.55	48.15
LSD (0.05)	0.402**	0.337**	1.315**	1.706**	0.019**	0.019**	0.8442**
CV (%)	3.8	5.57	3.83	3.41	5.17	3.06	1.53

(T): Turkey; ©: Cultivar; OC: Oil Content; **: Significant at $p < 0.01$.
16:0: Palmitic acid; 18:0: Stearic acid; 18:1: Oleic acid; 18:2: Linoleic acid: 18:3: Linolenic acid; 20:0 Arachidic acid.

Bhunia *et al.*, (2015) reported that the percentage of oleic acid varied between 38 and 50%, and that linoleic acid ranged from 18 to 43%. Although linolenic acid is one of the most important unsaturated fatty acids, the linolenic acid content was very low in all sesame accessions varying from 0.28 to 0.40% (the highest in Iran1 and Iran 2),with an average of 0.32%. Over a two-year period, the highest average oleic acid percentage was obtained from Kilis (T) (43.63%) and the lowest from the Iran 3 (36.14%) sesame accession. Over a two-year period, the highest average linoleic acid content was recorded in Egypt 1 (45.74%), and the lowest was in the Kilis (T) (39.83%) sesame accession (Table 5).Sesame has more unsaturated fatty acids than many other vegetable oils, and its higher proportion of unsaturated to saturated fatty acids makes it a potentially important dietary source of essential fatty acids (Bedigian, 2010). Linoleic acid is required for cell membranes, for transportation of cholesterol in the bloodstream, and for blood clotting (Salunkhe *et al.*, 1991).

In the present study, the total content of these unsaturated fatty acids was 83.9%. This value is similar to those reported by Uzun *et al.*, (2008) (83.1%) and Kurt *et al.*, (2016) (83%), higher than those reported by Bhunia *et al.*, (2015) (75%) and Yol *et al.*, (2016) (80.3%), and lower than those reported by Were *et al.*, (2006) (85.9%) and the World collection (Yermanos, 1972) (85.6%). A high level of unsaturated fatty acids increases oil quality for human consumption.

Palmitic and stearic acids were the predominant saturated fatty acids in sesame oil, and were in the range of 8.19 to 10.26% and 4.63 to 6.35%, respectively. Palmitic acid is used in industrial products such as soaps, esters, and plasticizers (Ndangui *et al.*, 2010).

Germ plasm, year and germ plasm x year effects were significant for all the fatty acids and oil contents. Most fatty acids did not differ significantly in their variation for the germ plasm x year interaction, while all the tested parameters showed significant variation in germ plasm (Table 6).

3.2. Correlations among oil content and fatty acid composition

Correlations between different traits are generally due to the presence of linked genes and the epistatic effect of different genes (Baloch *et al.*, 2014). The results of the correlation analyses of oil content and fatty acids in the sesame accessions examined are shown in Table 7. Oil content was negatively and significantly correlated in oleic and stearic acids, but not in palmitic and linoleic acids. A similar relationship between oil content and oleic acid has been reported in sesame seeds (Yol *et al.*, 2015; Were *et al.*, 2006).

Stearic acid was significantly positively correlated with oleic and arachidic acid, while it had an inverse association with both linoleic and linolenic acids. Such an association was also reported by Yol *et al.*, 2015. Linoleic acid was significantly negatively correlated with arachidic acid. Were *et al.*, (2006) also reported a similar relationship between oleic and arachidic acids. Oleic acid had a strong negative correlation with linoleic acid (r = -0.919) (Table 7). This was expected because linoleic acid is synthesized from oleic acid (Yol *et al.*, 2015). A similar finding has been reported by other researchers for other oilseed crops including peanut (Mora-Escobedo *et al.*, 2015) and soybean (Farno, 1996). The results indicated that different enzymatic processes of fatty acid synthesis are the principal determinant of the fatty acid composition in sesame seeds (Were *et al.*, 2006). This inverse relationship between oleic and linoleic acids may be helpful in evaluating varieties that are rich in either oleic acid or linoleic acid (Pleines and Friedt, 1988; Baydar *et al.*, 1999).

Table 6. Variance analysis of oil contents and fatty acid compositions of 24 germ plasm over 2 years

Variable	OC(%)	16:0	18:0	18:1	18:2	18:3	20:0
Accession	***	**	**	***	***	***	***
Year	**	**	NS	*	***	***	NS
Germ plasm x Year	***	NS	**	NS	NS	NS	***

*:Significant at p < 0.05; **: Significant at p < 0.01; ***: Significant at p < 0.001; NS: non-significant OC: Oil Content; 16:0: Palmitic acid; 18:0: Stearic acid; 18:1: Oleic acid; 18:2: Linoleic acid: 18:3: Linolenic acid; 20:0 Arachidic acid.

Table 7. Correlation among fatty acid compositions (% in oil) in different sesame accessions

	Palmitic	Stearic	Oleic	Linoleic
Stearic	−0.152			
Oleic	−0.096	0.304(**)		
Linoleic	−0.163	−0.403(**)	−0.919(**)	
Linolenic	0.082	−.058	−0.133	0.149
Arachidic	0.036	0.432(**)	0.134	−0.232(**)

**: 1%.

3.3. Unsaturated fatty acids and their de-saturation ratios

The nutritional quality of edible seed oils is determined ideally by the presence of a lower level of saturated fatty acids (SFA) [e.g. palmitic acid (C16:0), stearic acid (C18:0)], and a high level of unsaturated fatty acids [e.g. oleic acid (OA), linoleic acid (LA) and α-linolenic acid (ALA)]. Variations in the UFA/SFA ratio in different accessions are shown in Table 8**.** Taking into account all fatty acids, the average content of unsaturated fatty acids was 83.93%, the highest UFA value being obtained from the Iran 2 (84.82%) accession. A high level of unsaturated fatty acids (UFA) enhances the quality of oil for human consumption. In particular, a high level of linoleic acid in the oil decreases blood cholesterol levels and plays an important role in preventing atherosclerosis (Ghafoorunissa, 1994). Among the accessions, the highest O:L ratio was recorded in Kilis (T) (1.07); while the lowest was in Ethiopia (0.82).

It is difficult to evaluate suitable cultivars with beneficial health attributes solely on the basis of their phenotypic characteristics. The fatty acid biosynthetic pathway is highly inter-connected and any breeding modification will affect the entire system (Pleines and Friedt, 1988). Therefore, the two ratios were additionally developed and used to overcome this problem, the oleic de-saturation ratio (ODR) and the linoleic de-saturation ratio (LDR) (Bhunia *et al.*, 2015; Mondal *et al.*, 2015).

The variations in the ODR and LDR ratios are shown in Table 8. Among all the accessions, LDR values were found to be very low because of the low level of linolenic acid in sesame oil. The average ODR value was 0.53, while the average LDR value was 0.007. While the average ODR value found was higher than that reported by Bhunia *et al.*, (2015) (0.434) because of lower oleic acid content, the average LDR value was lower than that reported by Bhunia *et al.*, (2015) (0.013) because of higher linoleic acid and lower linolenic acid contents. Mondal *et al.*, (2010) reported that the mean value of ODR was 0.5, while the mean value of LDR was 0.01.

The oleic acid and linoleic acid ratio varied between 0.82 and 1.07. Among the accessions, the highest O/L ratio was 1.07 in Kilis (T), and the

Table 8. Range of variation in de-saturation, O/L acid, and UFA/SFA ratios in seed oil of different sesame accessions

Germ plasm	UFA/SFA	O/L	ODR	LDR
Kahramanmaras (T)	5.67	0.87	0.538	0.006
Balikesir-Kepsut (T)	5.51	0.92	0.522	0.007
Mugla-Koycegiz (T)	5.39	0.84	0.545	0.008
Kilis (T)	5.52	1.07	0.485	0.008
Bursa-Orhangazi (T)	5.39	0.96	0.511	0.008
Malatya-Ispendere (T)	5.46	0.86	0.540	0.007
Orhangazi-99 (T)©	5.58	0.87	0.531	0.007
India	5.64	0.89	0.512	0.007
Afghanistan	5.65	0.96	0.548	0.006
Libya	5.57	0.83	0.545	0.008
Greece 1	5.42	0.84	0.532	0.007
Greece2	5.39	0.94	0.529	0.007
Egypt 1	5.21	0.89	0.551	0.009
Egypt 2	5.39	0.90	0.517	0.007
Ethiopia	5.92	0.82	0.540	0.007
Zaire	5.45	0.86	0.543	0.007
Iraq	5.78	0.85	0.501	0.007
USA	5.80	1.01	0.538	0.008
Iran1	5.38	0.89	0.531	0.009
Iran2	5.94	0.97	0.509	0.009
Iran3	5.69	0.87	0.539	0.007
Iran4	5.92	0.83	0.548	0.007
Iran5	5.58	0.84	0.545	0.007
Pakistan	5.80	0.95	0.515	0.007

UFA: Unsaturated Fatty Acid; SFA: Saturated Fatty Acid; O:Oleic Acid; L:Linoleic Acid; ODR:Oleic Acid De-saturation Ratio; LDR: Linoleic Oleic Acid De-saturation Ratio;

lowest was 0.82 in Ethiopia because of higher linoleic acid contents. As can be seen in Table 8, the Turkish sesame accessions O/L ratio was higher than other countries.

4. CONCLUSION

In this study, considerable variation was found in oil content and fatty acid composition among sesame accessions from different origins. The predominant unsaturated fatty acids were linoleic acid and oleic acid, and linoleic acid contents were higher than oleic acid in all sesame accessions except the Kilis (T) accession. The Turkish sesame accessions' O/L ratio was higher than other countries. Linoleic acid is an essential fatty acid for humans because it cannot be synthesized in the body but must be obtained from dietary sources. Sesame oil is considered a premium oil because it contains a high level of linoleic acid. The identified diversity in fatty acid contents is useful for the identification of better parents with high linoleic acid and oleic acid contents for developing elite sesame varieties with traits which are beneficial to consumer health. These sesame accessions are valuable in sesame breeding programs for high oil content and good fatty acid composition.

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