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Original Research

Determination of Fatty Acid, Tocopherol and Lignan Composition of Sesame (*Sesamum indicum* L.) Genotypes from Different Countries in Mediterranean Region Conditions

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Abstract

Sesame is one of the neglected crops. As a result, there are not many studies on the fatty acid, tocol and lignan composition of sesame genotypes under Mediterranean climate conditions. This study aimed to evaluate the diversity in fatty acid, lignan and tocol composition among 50 different sesame accessions from Türkiye and 12 other countries under Mediterranean climate conditions. The content of palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, α-tocopherol, γ-tocopherol, α-tocotrienol, total tocopherol, sesamin, sesamolin, sesamol varied between 8.39-10.11%, 4.19-5.36%, 35.83-43.49%, 40.64-48.8%, 0.28-0.49%, 1.08-2.79 µg/g, 41.5-75.74 µg/g, 0.96-1.8 µg/g, 42.93-76.92 µg/g, 2.34-14.31 mg/g, 0.23-1.81 mg/g, 0-0.59 mg/g respectively. While the sesamin content of the sesame genotypes used in the study was higher than previously reported values, it was determined that the sesamol content was at very low levels. The sesame genotypes are rich in sesamin content and can be used as parents in breeding programs. The results obtained from the study showed that the lignan and tocol composition of the cultivars produced in Türkiye were not at the desired levels. Therefore, improving the lignan and tocol composition of the cultivars in the breeding programs designed to obtain new cultivars will benefit consumers in Türkiye, which consumes sesame extensively.

Keywords: sesame, fatty acid, sesamol, sesamin, tocols, adaptation

Introduction

Sesame is one of the oldest and most important oil crops known. The cultivation of sesame dates back to 3500 years. During the last period, sesame cultivation was carried out in more than 60 countries, but it is consumed in different amounts in almost all countries [1]. The most important reason for the increasing interest in sesame seeds and oil is the nutritional properties of sesame and it positively effects on human health. Sesame seeds are used in bakery products and also made into tahini and halva. Moreover, it is used in industries such as pesticides, paint, medicine, cosmetics, perfumery, and soap. Sesame has anti-carcinogenic, anti-tumor, anti-aging, and anti-hypertension properties.

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Sesame seeds contain 40-60% oil, 18-25% protein, 13.5% carbohydrates and 5% ash. In addition, sesame seeds are rich in elements such as Ca, Fe, Zn, and Se [1]. It also contains sesame-specific lignans such as sesamin, sesamolin and sesaminol. In addition to lignans, sesame seeds, which have antioxidative and health-promoting properties, also contain multiple tocopherol homologs such as α, δ, γ, and tocotrienols. The sesame seeds are commonly known as the 'Queen of oil seeds', probably due to their high oil yield, pleasant taste, high nutritional and therapeutic values, and resistance to oxidation and rancidity [2].

Unsaturated fatty acids make up about 85% of the oil in sesame seeds. However, sesame oil is resistant to oxidative degradation when compared to other vegetable oils. Its superior anti-oxidative property is not only due to its high γ-tocopherol content but also due to the sesame-specific lignans it contains such as sesamol, sesamin, and sesamolin. These lignans have numerous health benefits such as anti-carcinogenic, anti-inflammatory, anti-aging, anti-neuropathic, antihypertensive, cardioprotective and hypocholesterolemia [3].

The richness of unsaturated fatty acids in sesame oil makes it a very high-quality oil in terms of nutrition and health. It is directly related to cardio-protective, hypo-lipidemic, anti-atherogenic and anti-inflammatory effects [4].

Tocopherols are natural antioxidants that hamper oil oxidation. In addition to having an important nutritional function for humans as a source of vitamin E, tocopherols absorb free radicals and can prevent from different diseases [5]. Vitamin E has been recognized as an important dietary component with anti-aging function. It is known that this feature of vitamin E is due to the α-tocopherol in it. The highest tocopherol content in sesame seeds belongs to γ-tocopherol, and α-tocopherol is present in tiny amounts. However, studies in rats have shown that γ-tocopherol in sesame seed exhibits vitamin E activity equal to that of α-tocopherol through a synergistic interaction with sesame seed lignans [6].

Although sesame is generally grown in developing countries, it is consumed in different amounts in almost every country. Therefore, determining the nutritional content of sesame genotypes is important in providing necessary nutritional information to consumers. In addition, the characterization of genetic resources in terms of these features is of great importance in providing genetic material that breeders can use in the development of varieties with higher nutritional contents [1, 7, 8]. Previous studies on sesame were generally limited to the quantification of lignans alone or oil or tocopherols alone, lignans with fatty acids, or tocopherols with fatty acids [9-15]. Regarding the fatty acids, tocols and lignan contents of sesame, no reports have been found examining these three oil traits together. Hence, the present study aimed to evaluate the extent of variability for fatty acids, lignans tocopherols, and tocotrienols (tocols) in the 50 different sesame genotypes originating from Türkiye and 12 different countries.

Material and Methods

Plant Material

Fifty sesame genotypes were used as plant material in this study. All sesame genotypes were sown at the Experimental Farm of Cukurova University, in Adana (Türkiye). Adana has mild and rainy winters, hot and dry summers, and frequent, heavy and short-term rainfall, especially in autumn, which is a typical example of the Mediterranean climate. Before planting, 200 kg/ha of diammonium phosphate (36 kg/ha N, 92 kg/ha P) fertilizer was applied, while ammonium nitrate (33 %N) at the rate of 200 kg/ha was applied before the first irrigation. Sesame seeds were sown in the third week of June. The accessions were grown in two-row plots of 3 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 as needed. Weeding was carried out by hand and no herbicides were applied during the experiment. All the plants were harvested by hand in the last week of September, 2020 [1].

Oil Extraction and GC Analysis

The samples of 50 sesame genotypes were subjected to oil samples extracted by cold press. Sesame seeds were cold-pressed at room temperature with the press (Karaerler NF 500) at 10 MPa for 10 minutes where the temperature was kept below 40ºC. The oils were filtered through a Whatman No. 2 filter paper. The extracted oil samples were kept in glass sample bottles in the fridge until analysis could take place.. An oil sample of 500 mg was dissolved in 2 ml isooctane followed by 1.5 ml of 0.5 M methanolic NaOH (99.6%, Sigma). The tube was then vortexed and held in boiling water for 7 min and allowed to cool to room temperature. Two ml of BF3 (99.99% Boron trifluoride, Sigma) 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 (Merck), 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 140ºC for 5 min, then raised to 200ºC at a rate of 4ºC/min and to 220ºC at a rate of 1ºC/min, while the injector and the detector temperatures were set at 220ºC and 280ºC, respectively [16].

Analysis of Tocols and Lignans

Tocols and lignans were analysed in the oil samples extracted by cold press (Karaerler NF 500) with a High Pressure Liquid Chromatography (HPLC) device (Agillent Technologies 1200) with UV detector. HPLC conditions in the analysis of tocols, Column: Inertsil NH2 250 mm x 4.6 mm – 5 µm, Mobile phase: n-hexane/acetic acid/IPA (1000mL/5mL/6mL), Column temperature: 20ºC, Wavelength: 296 nm, Flow rate: 1 mL, Injection volume: 10 µL (TS ISO, 2016). HPLC conditions in the analysis of lignans, Column: Prodigy ODS3 100A 250 mm x 4.6 mm – 5 µm, Mobile phase: methanol/water (70 mL/30 mL), Column temperature: 30ºC, Wavelength: 290 nm, Flow rate: 1 mL, Injection volume: 10 µL [17]. A calibration was performed between 0.005 and 0.5 mg/L. The limit of detection (LOD) and limit of quantification (LOQ), expressed in mg/g, were found to be 0.05(LOD)/0.075(LOQ) for sesamolin and sesamin, and 0.01(LOD)/0.02(LOQ) for sesamol.All chemicals used in the analyses are Merk brand, and the standards are Sigma Aldrich (Sesamolin Product Number: SMB00701, Sesamin Product Number: 59867, Sesamol Product Number: S3003) and ChromaDex (Tocotrienol and Tocopherol Mixture Lot Number: 00020329-00569).

Statistical Analysis

The statistical software XLSTAT (www.xlstat.com) was employed to examine the mean, maximum, minimum, standard deviation, and correlation pertaining with significance level alpha=0.05 to all seven traits under investigation. Additionally, Principal Component Analysis (PCA) was conducted utilizing the same software. A biplot graph was generated using XLSTAT.

Results and Discussion

Fatty Acid Composition

Fatty acid composition is one of the important features used to indicate the nutritional value of oils. The sesame seed oil contains high amounts of monounsaturated fatty acids such as oleic acid (35-54%) and polyunsaturated fatty acids such as linoleic acid (39-59%) [18]. The fatty acid compositions varied significantly among the tested sesame accessions (Table 1). USA 2 genotype at 43.49% exhibited the highest oleic acid (C18:1) content while Pakistan 2 at 35.83% exhibited the lowest oleic acid content in the study. The linoleic acid (C18:2) contents varied between 40.64-48.8% with a mean of 43.29%. When the average oleic (40.61%) and linoleic acid (43.29%) contents of the studied sesame genotypes were examined, it was found that the content of linoleic acid was higher. Linoleic acid content in earlier reports by Morris et al., (2021) [19], and Kurt (2018) [16] was higher, while lower oleic acid contents than that found in the present study. Teklu et al. (2022) [20] found in their analysis of 100 sesame genotypes from Ethiopia that the oleic acid percentage varied between 36.76%-48.84%, while the linoleic acid percentage varied between 36.56%-47.144%. Zahran et al. (2020) [21] reported that oleic acid content varied from 37.15% to 46.61%, while linoleic acid varied from 37.49% to 44.33% in their study with 5 new sesame lines and one commercial genotype in Egypt. Kim et al., (2024) [22] found that, oleic and linoleic acids contents were higher than that found in the present study. Comini et al., (2023) [23] found oleic and linoleic acids contents were lower than present study. Diyarbakir-Bismil genotype at 0.49% exhibited the highest linolenic acid content, while Diyarbakir-Bismil-Bakacak genotype at 0.28% had the lowest linolenic acid content. While previous studies by Rounizi et al., (2021) [24], Comini et al., (2023) [23], Zangui et al., (2023) [25] reported that the linoleic acid content was higher than the current study, it was found to be lower in the study conducted by Kim et al., (2024) [22], Zahran et al., (2020) [21].

Palmitic acid was the predominant fatty acid with stearic acid in sesame oil and varied between 8.39-10.11% and 4.19-5.36% with averages of 9.37 and 4.72% respectively. Denizli-Acipayam and Diyarbakir Ergani Ziyaret Köy have higher palmitic and stearic acid content than averages. Kurt (2015) [26] reported that palmitic and stearic acid contents varied between 8.63-9.77% and 4.93-5.94% respectively. Agidew et al., (2021) [27] found palmitic acid content varied between 9.34-11.18%, while stearic acid content varied from 5.78 to 6.52%. Were et al. (2006) [28] reported that average palmitic acid content (8.24%) was lower, while stearic acid content (4.89%) was higher than the present study. These differences in the aforementioned results may have been observed due to different reasons such as the genetic potential of the materials used in the studies, soil conditions, the cultural practices, and environmental conditions.

Tocols and Lignans Composition

Edible oils mainly consist of fatty acids in the form of triacylglycerols, which produce energy for the human body during metabolism. In addition, edible oils are sources of minor compounds such as tocopherols, tocotrienols, or both (tocols), carotenoids, and phytosterols [29]. Interest in tocol studies has increased dramatically in recent years, most likely to increase awareness of the health effects of individual food items and diets [30]. Tocol-related compounds, tocopherols (α, β, δ, γ) and tocotrienols, belonging to the vitamin E family, are important bioactive components in vegetable oils, mainly due to their antioxidative effects [29].

Sesame is one of the neglected crops. As a result, there are not many studies on the tocol content of sesame genotypes. Sesame seed total tocol contents vary from one germplasm to another. As can be seen

Table 1. Fatty acids composition of sesame genotypes.

Genotypes	C16:0	C16:1	C18:0	C18:1	C18:2(ω-6)	C18:3(ω-3)	C20:0
Sanliurfa- Siverek- Basdegirmen 1 [T]	9.34	0.14	4.89	41.58	42.59	0.31	0.52
Sanliurfa-Siverek- Basdegirmen 2 [T]	9.47	0.14	4.96	41.32	42.43	0.33	0.06
Denizli-Dazkiri [T]	9.72	0.13	4.70	38.34	45.56	0.32	0.55
Denizli-Acipayam [T]	9.55	0.13	5.08	42.95	**40.64**	0.32	0.57
Sanliurfa- Bozova-Hasmersar [T]	9.69	0.14	4.69	39.84	44.05	0.33	0.53
Antalya-Finike [T]	9.90	0.14	4.53	38.59	45.31	0.32	0.51
Sanliurfa-Akziyaret [T]	9.40	0.14	4.55	42.27	42.12	0.35	0.50
Aydın-Çine [T]	9.48	0.13	4.81	41.05	43.02	0.34	0.55
Adıyaman-Gölbaşı [T]	9.27	0.14	4.91	39.71	44.52	0.28	0.55
Antalya-Konyaaltı [T]	9.50	0.13	4.55	41.03	43.33	0.33	0.51
Adana-Ceyhan [T]	9.61	0.14	4.66	41.66	42.45	0.31	0.50
Mardin [T]	9.93	0.14	4.60	41.08	42.70	0.36	0.51
Diyarbakir-Bismil- Bakacak [T]	10.07	0.14	4.55	40.01	43.82	**0.28**	0.50
Diyarbakir- Bismil Yukari Harim Köy [T]	9.82	0.14	4.49	38.90	45.19	0.31	0.51
Adana-Yumurtalik [T]	**10.11**	**0.15**	4.48	40.13	43.66	0.34	0.51
Batman [T]	9.80	0.13	5.06	42.29	41.31	0.31	0.55
İcel-Tarsus [T]	9.50	0.13	4.60	38.82	45.48	0.30	0.52
Diyarbakir- Ergani- Dağarası Köyü [T]	9.47	0.14	4.68	41.83	42.46	0.29	0.51
Diyarbakir- Ergani Ziyaret Köy [T]	10.08	0.14	4.89	41.29	42.13	0.28	0.56
Greece 1	9.12	0.11	4.78	40.93	43.47	0.33	0.50
Pakistan 1	9.53	0.11	**4.19**	37.88	46.90	0.34	0.47
Pakistan 2	9.74	0.12	4.25	**35.83**	48.69	0.34	0.48
Iran	9.56	0.12	4.23	35.97	**48.80**	0.33	0.44
Diyarbakir-Bismil [T]	9.69	0.13	4.51	39.72	44.27	**0.49**	0.51
Baydar-2001 [C]	9.32	0.12	4.77	42.12	41.91	0.44	0.53
Batem-Uzun [C]	9.27	0.13	4.64	41.65	42.48	0.40	0.49
Batem-Aksu [C]	8.86	0.12	4.60	42.56	41.97	0.45	0.47
Boydak [C]	9.09	0.11	4.88	41.90	41.61	0.38	0.49
Gölmarmara [C]	9.11	0.12	4.76	38.99	43.22	0.37	0.50
Tanas [C]	9.48	0.12	4.86	40.53	42.71	0.44	0.52
Hatipoğlu [C]	9.06	0.11	4.78	42.05	41.35	0.44	0.48
Tan-99 [C]	9.30	0.12	4.66	40.63	41.19	0.42	0.50
Özberk [C]	9.22	0.12	4.68	40.95	42.58	0.40	0.50
Mozambik	9.05	0.11	4.74	40.61	43.33	0.36	0.51
Israel	9.17	0.11	4.88	38.89	44.28	0.35	0.54
Pakistan 3	9.21	0.11	**5.36**	41.94	41.69	0.34	0.58
Greece 2	9.20	0.11	4.90	41.97	40.89	0.37	0.51
Russia 1	9.03	0.12	4.72	39.43	43.26	0.34	0.51
Russia 2	8.78	0.12	4.62	41.27	43.24	0.36	0.52
Libya	8.75	0.11	4.75	39.75	45.01	0.32	0.53

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Egypt	8.91	0.11	5.11	39.75	43.76	0.32	0.58
Iraq	8.81	0.11	4.81	40.89	43.70	0.35	0.55
S. America	10.08	0.12	4.63	39.32	44.25	0.35	0.54
USA 1	9.04	0.12	4.63	41.98	42.33	0.41	0.55
Afghanistan	**8.39**	0.11	4.88	42.29	42.60	0.37	0.55
Manisa-Selendi [T]	8.75	0.12	4.85	42.92	41.45	0.39	0.54
USA 2	8.90	0.12	4.61	**43.49**	40.99	0.43	0.53
Kepsut-99 [C]	9.32	0.12	4.60	41.67	42.38	0.48	0.54
Sarisu [C]	9.47	0.13	4.67	40.48	43.36	0.45	0.53
Osmanlı-99 [C]	9.75	0.13	4.82	39.57	43.82	0.46	0.55
Max.	10.11	0.15	5.36	43.49	48.8	0.49	0.58
Min.	8.39	0.11	4.19	35.83	40.64	0.28	0.06
Ave.	9.37	**0.12**	**4.72**	**40.61**	**43.29**	**0.36**	**0.51**

[C]: Cultivar; [T]: Türkiye

in Table 2, the mean of α-tocopherol content ranged across studied sesame genotypes was 1.63 µg/g, varying from 1.08 to 2.79 µg/g. The highest value belongs to the Turkish cultivar, Batem-Aksu, and Adıyaman-Gölbaşı exhibited the lowest α-tocopherol content. α-tocotrienol content varied between 0.96-1.8 µg/g, Türkiye-Aydın-Çine and Türkiye-İçel-Tarsus respectively. γ-tocopherol shows a higher antioxidant capacity compared to α-tocopherol [31], which is important for the industrial use of sesame oil. According to Jiang et al., (2001) [32], γ-tocopherol is the most abundant form in sesame seeds, the predominant form of vitamin E in human and animal tissues, and may be important for human health compared to α-tocopherol, which is the main form in supplements. γ-tocopherol content ranged from 41.5 to 75.74 µg/g with an average of 52.43 µg/g in studied sesame genotypes seeds.

Lignans in sesame seeds have attracted the attention of nutritional scientists and healthcare professionals for their health-promoting activities such as lowering blood sugar and cholesterol levels, preventing cardiovascular diseases, Alzheimer's and cancer, and relieving post-menopausal syndrome [33, 34]. The ability of sesamin to suppress tumor growth [35]. Yokota et al., 2007 [36] suggest that sesamin could even be developed as a therapeutic agent. Sesame oil and lignans are components of creams and body oils [37, 38]. In addition to nutritional, cosmetic, and health-promoting use, sesame lignans (especially sesamol) are used as an additive in insecticides due to their synergistic effect and low-grade oil is used for the manufacture of soaps, perfumes, and paints in the industry. Although sesame lignans have important effects on human health, unfortunately there are not many studies investigating the lignan contents of sesame genotypes and using a large number of sesame genotypes. There was significant variation in lignan contents among the sesame genotypes as shown in Table 3. The mean of sesamin content ranged across studied sesame genotypes was 6.65 mg/g, varying from 2.34 to 14.31 mg/g. The highest value belongs to the Sanliurfa-Siverek-Basdegirmen 1, the Turkish cultivar Osmanlı-99 exhibited the lowest sesamin content. Sesamin content values range in the present study were higher than those reported by Kim et al. 2006 [39] (0.38-5.12 mg/g), Wu et al. 2017 (1.7-5.1 mg/g) [40], Zhu et al. 2018 (2.16-7.37 mg/g) [41], Ajit et al., (2019) (0.08-2.58 mg/g) [42], Dar et al. 2019 (2.1-5.98 mg/g) [43], Xu et al. 2021 (0.33-7.52 mg/g) [44] and Comini et al., (2023) (0.37-8.72 mg/g) [23]. While the highest value of sesamolin content, another major lignan, was obtained from the Israel genotype (1.81 mg/g), the lowest value was obtained from the Turkish variety Osmanlı-99 (0.23 mg/g). The range of sesamolin content values in this study was found to be considerably lower than the values in previously reported studies [Moazzami et al. 2007 (1.67-8.04 mg/g) [45], Wang et al. 2012 (0.93-6.96 mg/g) [46], Ajit et al., (2019) (0.08-2.58 mg/g) [42], Dar et al. 2019 (1.52-3.76 mg/g) [43], Comini et al., (2023) (0.6-7.04 mg/g) [23]. While the highest sesamol value was obtained from the Turkish genotype Denizli-Acipayam, sesamol could not be detected in 15 of the 50 genotypes studied. These are 8 of the 15 genotypes whose sesamol could not be detected are Turkish cultivars. Other Turkish cultivars used in the study, Tanas, contain 0.01 mg/g and Kepsut-99 contains 0.04 mg/g sesamol. When the present study is compared with previous studies, the sesamol ratio we detected in our results is at very low levels [14, 43, 47]. Reports on the variability of the sesame lignans contents in sesame seeds indicated that these lignans are affected by genetics, cultivars, origin, agronomic conditions and practices, environmental stresses, and other seed traits such as seed color [43, 46-49].

Table 2. Tocol composition of sesame genotypes.

Genotypes	α-Tocopherol (µg/g oil)	α-Tocotrienol (µg/g oil)	γ-Tocopherol (µg/g oil)	Total Tocopherol (µg/g oil)
Sanliurfa- Siverek- Basdegirmen 1 [T]	1.52	1.40	58.68	60.20
Sanliurfa-Siverek- Basdegirmen 2 [T]	1.43	1.34	**41.50**	**42.93**
Denizli-Dazkiri [T]	1.34	1.20	53.16	54.50
Denizli-Acipayam [T]	1.55	1.35	50.43	51.97
Sanliurfa- Bozova-Hasmersar [T]	1.32	1.03	48.51	49.83
Antalya-Finike [T]	1.30	1.02	52.93	54.23
Sanliurfa-Akziyaret [T]	1.58	1.16	51.24	52.82
Aydın-Çine [T]	1.18	**0.96**	46.65	47.82
Adıyaman-Gölbaşı [T]	**1.08**	0.98	51.17	52.25
Antalya-Konyaaltı [T]	1.41	1.04	53.44	54.84
Adana-Ceyhan [T]	1.53	1.33	50.74	52.26
Mardin [T]	1.26	1.18	52.11	53.37
Diyarbakir-Bismil- Bakacak [T]	1.21	1.26	53.02	54.22
Diyarbakir- Bismil Yukari Harim Köy [T]	1.15	1.02	58.45	59.60
Adana-Yumurtalik [T]	1.37	1.36	58.41	59.78
Batman [T]	1.43	1.18	59.10	60.52
İcel-Tarsus [T]	1.18	**1.80**	**75.74**	**76.92**
Diyarbakir- Ergani- Dağarası Köyü [T]	1.47	1.48	73.34	74.81
Diyarbakir- Ergani Ziyaret Köy [T]	1.35	1.33	66.45	67.80
Greece 1	2.07	1.63	53.03	55.10
Pakistan 1	1.73	1.31	62.16	63.89
Pakistan 2	1.27	1.48	60.66	61.93
Iran	1.55	1.37	56.64	58.19
Diyarbakir-Bismil [T]	2.49	1.46	52.87	55.37
Baydar-2001 [C]	2.14	1.26	46.15	48.29
Batem-Uzun [C]	1.82	1.31	47.37	49.18
Batem-Aksu [C]	**2.79**	1.24	42.44	45.23
Boydak [C]	1.79	1.36	47.68	49.47
Gölmarmara [C]	1.66	1.32	48.90	50.56
Tanas [C]	1.57	1.29	44.45	46.01
Hatipoğlu [C]	2.31	1.39	45.58	47.89
Tan-99 [C]	1.73	1.47	48.49	50.22
Özberk [C]	1.73	1.30	48.20	49.94
Mozambik	1.56	1.30	49.79	51.35
Israel	1.56	1.25	53.64	55.20
Pakistan 3	1.54	1.35	47.43	48.97
Greece 2	1.63	1.31	49.32	50.95
Russia 1	1.75	1.39	49.22	50.96
Russia 2	1.57	1.37	50.48	52.05

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Libya	1.66	1.25	47.78	49.43
Egypt	1.37	1.27	49.47	50.83
Iraq	1.84	1.44	59.27	61.11
S. America	1.56	1.24	56.11	57.67
USA 1	1.55	1.33	54.43	55.97
Afghanistan	1.58	1.40	49.83	51.40
Manisa-Selendi [T]	1.50	1.32	45.64	47.14
USA 2	1.86	1.29	48.90	50.76
Kepsut-99 [C]	2.63	1.47	46.65	49.28
Sarisu [C]	1.93	1.35	50.97	52.90
Osmanlı-99 [C]	2.18	1.53	52.76	54.94
Max.	2.79	1.63	75.74	76.92
Min.	1.08	0.96	42.44	42.93
Ave.	1.63	1.31	52.43	54.06

Table 3. Lignans composition of sesame genotypes.

Genotypes	Sesamol (mg/g oil)	Sesamin (mg/g oil)	Sesamolin (mg/g oil)
Sanliurfa- Siverek- Basdegirmen 1[T]	0.28	**14.31**	1.45
Sanliurfa-Siverek- Basdegirmen 2 [T]	0.24	6.97	0.57
Denizli-Dazkiri [T]	0.24	7.82	0.55
Denizli-Acipayam [T]	0.59	11.42	1.49
Sanliurfa- Bozova-Hasmersar [T]	0.33	8.03	0.65
Antalya-Finike [T]	0.19	6.19	0.44
Sanliurfa-Akziyaret [T]	0.18	8.06	0.71
Aydın-Çine [T]	0.20	8.65	1.22
Adıyaman-Gölbaşı [T]	0.14	9.22	1.50
Antalya-Konyaaltı [T]	0.22	5.29	0.68
Adana-Ceyhan [T]	0.17	7.45	0.61
Mardin [T]	0.18	7.93	0.60
Diyarbakir-Bismil- Bakacak [T]	0.26	9.54	0.82
Diyarbakir- Bismil Yukari Harim Köy [T]	0.46	9.25	0.75
Adana-Yumurtalik [T]	0.23	9.15	0.57
Batman [T]	0.15	10.35	1.65
İcel-Tarsus [T]	0.13	10.47	0.99
Diyarbakir- Ergani- Dağarası Köyü [T]	0.19	6.10	0.75
Diyarbakir- Ergani Ziyaret Köy [T]	0.14	9.34	1.50
Greece 1	ND	9.40	0.78
Pakistan 1	ND	5.53	0.99
Pakistan 2	0.09	5.38	1.40
Iran	ND	5.77	1.59
Diyarbakir-Bismil [T]	0.01	3.59	0.60

→

Baydar-2001 [C]	ND	3.38	0.39
Batem-Uzun [C]	ND	3.71	0.41
Batem-Aksu [C]	ND	3.82	0.42
Boydak [C]	ND	6.77	0.74
Gölmarmara [C]	0.01	5.45	0.78
Tanas [C]	0.01	6.73	0.48
Hatipoğlu [C]	ND	5.32	0.60
Tan-99 [C]	0.01	4.36	0.42
Özberk [C]	ND	4.20	0.37
Mozambik	0.02	8.83	1.51
Israel	0.05	11.38	**1.81**
Pakistan 3	0.03	4.65	1.10
Greece 2	0.03	4.63	0.68
Russia 1	0.01	9.35	1.76
Russia 2	ND	8.52	1.46
Libya	ND	3.03	0.52
Egypt	0.01	7.81	0.73
Iraq	ND	5.09	1.21
S. America	0.11	2.61	1.09
USA 1	0.09	2.90	0.88
Afghanistan	0.02	9.10	1.22
Manisa-Selendi [T]	0.01	4.47	0.65
USA 2	ND	3.21	0.47
Kepsut-99 [C]	0.04	2.96	0.37
Sarisu [C]	ND	2.91	0.32
Osmanlı-99 [C]	ND	**2.34**	**0.23**
Max.	0.59	14.31	1.81
Min.	0	2.34	0.23
Ave.	0.1	6.65	0.87

[C]: Cultivar; [T]: Türkiye; ND: Not Determined

Principal Component Analysis

Principal component analysis (PCA) is mainly used to quantify the pattern and degree of variations among the different populations to evaluate the evolutionary trends and understand the relative participation of different components [50]. In this study, principal component analysis (PCA) was performed to determine the contribution of each trait to the overall variation observed in fatty acid, lignan, and tocol compositions. Using PCA based on the correlation matrix, we determined eigenvalues, the percentage of variability explained by a single eigenvector, and the cumulative variations explained by the first five eigenvectors (Table 4). These five PCs accounted for a total of 84.57% of the overall variations. Maximum variations were contributed by PC1 which accounted for a total of 33.344% variations and linolenic acid was the main contributor of variations with 0.808 value in this PC. PC2 accounted for a total of 18.72% variations and stearic acid was main contributor with 0.689 value in this PC . PC3 and PC4 accounted for a total of 14.611% and 10.508% variations, while sesamolin and α-tocotrienol were chief variation contributors with 0.633 and 0.461, respectively in these PCs. Minimum variations were contributed by PC5.

Table 4. Eigenvectors, eigenvalues, individual and cumulative percentages of variation explained by the first five principal components (PC) of sesame genotypes.

	PC1	PC2	PC3	PC4	PC5
Palmitic	-0.632	-0.043	-0.535	0.270	0.092
Palmitoleic	-0.567	0.308	-0.580	0.344	-0.046
Stearic	0.269	0.689	0.417	0.026	-0.040
Oleic	0.530	0.629	0.121	0.457	-0.022
Linoleic	-0.548	-0.661	-0.103	-0.442	0.025
Linolenic	0.808	-0.306	-0.211	0.186	0.107
Arachidic	-0.030	0.027	0.394	0.162	0.876
α-Tocopherol	0.747	-0.336	-0.025	0.271	-0.048
α-Tocotrienol	0.149	-0.485	0.463	0.461	-0.436
γ-Tocopherol	-0.743	-0.346	0.309	0.434	0.039
Total Tocopherol	-0.716	-0.371	0.314	0.457	0.037
Sesamol	-0.629	0.522	-0.309	0.147	-0.018
Sesamin	-0.612	0.476	0.342	-0.078	-0.205
Sesamolin	-0.474	0.139	0.633	-0.322	-0.057
Eigenvalue	4.668	2.621	2.046	1.471	1.034
Variability (%)	**33.344**	18.720	14.611	10.508	7.387
Cumulative %	33.344	52.064	66.675	77.184	84.571

Correlations Among Fatty Acid, Tocol, and Lignan Composition

The results of the correlation analyses of fatty acids, lignans and tocols in the 50 sesame genotypes examined (at significance level of *alpha = 0.05*) are shown in Table 5. Among the studied oil parameters, palmitic acid stands out as the highest correlated parameter with other oil parameters. While there was a positive and significant correlation with palmitoleic, linoleic, α-tocopherol, total tocopherol and sesamol, it has been found to have a negative and significant correlation with stearic acid, oleic acid, linolenic acid and α-tocopherol. A similar relationship between palmitic acid and stearic acid, palmitic acid and sesamol has been reported in sesame seeds [44]. While there was a positive correlation between stearic acid and oleic acid, it was determined that there was a positive correlation between γ-tocopherol and total tocopherol. Such a correlation between these fatty acids were also reported by Were et al., (2006) [28], Kurt (2018) [16], and Teklu et al., (2022) [20], Zongui et al., (2023) [25]. Morris et al., (2021) [19] also reported a similar relationship between stearic acid and γ-tocopherol. The strong negative correlation between oleic acid and linoleic acid has been reported by many researchers [16, 22, 51] and the results obtained from the present study are also consistent. Additionally, oleic acid was found to have a positive correlation with α-tocopherol and a negative correlation with γ-tocopherol and total tocopherol. Unlike oleic acid, linoleic acid has been found to have a positive correlation with γ-tocopherol and total tocopherol. α-tocopherol, on the other hand, stands out as an oil quality feature that has the most negative correlation with the others among the studied features. It was determined that there was a positive correlation between α-tocopherol and α-tocotrienol, and a negative correlation between γ-tocopherol, total tocopherol, sesamol, sesamin and sesamolin. In the study, it was found that there was a positive correlation between sesamin and sesamolin, and between sesamin and sesamol. In the light of this information obtained, it can be said that increasing the amount of sesamin in breeding programs may contribute to the increase of the sesamol and sesamolin [15, 52-53].

Conclusion

Sesame, a valuable vegetable oil, is known to have numerous beneficial properties for applications in the food industry. I identified considerable variation in studied oil parameters of 50 sesame genotypes under Mediterranean climate conditions. While the sesamin content of the sesame genotypes used in the study was higher than previously reported values, it was determined that the sesamol content was at very low levels. The sesame genotypes are rich in sesamin content and can be used as parents in breeding

Table 5. Correlation among fatty acids, lignans and tocols in the 50 sesame genotypes.

Variables	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Linolenic	Arachidic	α-Tocopherol	α-Tocotrienol	γ-Tocopherol	Total Tocopherol	Sesamol	Sesamin
Palmitoleic	**0,706**												
Stearic	**-0,301**	-0,178											
Oleic	**-0,376**	-0,026	**0,523**										
Linoleic	**0,293**	0,029	-0,614	-0,934									
Linolenic	**-0,279**	**-0,340**	-0,092	0,260	**-0,294**								
Arachidic	-0,062	-0,169	0,137	0,072	-0,071	0,026							
α-Tocopherol	**-0,332**	**-0,396**	-0,058	**0,288**	-0,272	**0,795**	-0,016						
α-Tocotrienol	-0,193	**-0,321**	-0,025	-0,011	0,000	0,227	-0,078	**0,374**					
γ-Tocopherol	**0,398**	0,270	**-0,297**	**-0,348**	**0,403**	**-0,500**	0,198	**-0,362**	**0,324**				
Total Tocopherol	**0,387**	0,253	**-0,306**	**-0,339**	**0,396**	**-0,465**	0,201	**-0,314**	**0,351**	**0,999**			
Sesamol	**0,534**	**0,679**	0,028	0,013	0,006	**-0,540**	-0,050	**-0,519**	**-0,371**	0,231	0,207		
Sesamin	0,151	**0,310**	0,226	-0,044	0,034	**-0,657**	0,039	**-0,526**	-0,079	**0,302**	**0,279**	**0,540**	
Sesamolin	-0,053	-0,116	0,159	-0,209	0,215	**-0,519**	0,152	**-0,380**	-0,005	**0,336**	**0,321**	0,139	**0,614**

Values in bold are different from 0 with a significance level *alpha = 0.05* programs. Sesamol was not detected in almost all of the cultivars from Türkiye. In addition, it was determined that the γ-tocopherol contents of these cultivars were below the average value. The same applies to sesamin and sesamolin. The only exception here is that the Osmanlı-99 cultivar has the highest sesamin content. The results obtained from the study showed that the lignan and tocol composition of the cultivars produced in Türkiye were not at the desired levels. Therefore, aiming to improve the lignan and tocol composition of the cultivars in the breeding programs designed to obtain new cultivars will benefit consumers in Türkiye, which consumes sesame extensively. In this context, determining the genetic diversity of parameters in sesame oil that have positive effects on human nutrition and health is of great importance for determining the parents to be selected for these characteristics. Besides, these sesame genotypes are valuable for developing QTL mapping populations due to wide variation.

Among the oil parameters examined, palmitic acid stands out as the parameter with the highest correlation with other oil parameters. In contrast, α-tocopherol stands out as the oil quality feature with the highest negative correlation among other parameters. Studying a large number of sesame genotypes and different traits such as fatty acids, tocols and lignans will contribute to supporting the correlations we detected between these traits.

Among the genotypes, Sanliurfa-Siverek-Basdegirmen 1 genotype has a total unsaturated fatty acids rate of 85%, sesamin 14.31 mg/g, sesamolin 1.45, a-tocopherol 1.52 m/g, a-tocotrienol 1.4 m/g and g-tocopherol 58.68 m/g. was the prominent genotype.

Conflict of Interest

The authors declare no conflict of interest.

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Data Availability Statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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