CHANGES IN THE FATTY ACIDS COMPOSITION OF SEED OIL IN DIFFERENT CULTIVARS OF SESAME UNDER FOLIAR APPLICATION OF SULFUR

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Abstract

Sulfur plays an important role in the determination of seed yield (SY) and quality of oilseed crops. However, the effect of foliar application of sulfur is not yet known on SY and oil yield (OY) of sesame genotypes. Therefore, a field factorial experiment based on a randomized complete block design was conducted during two years of 2017 and 2018. Effects of foliar application of sulfur at five concentrations, namely S1, S2, S3, S4, and S5 indicating 0, 1, 2, 4, and 8 mg/L were investigated on endemic and non-endemic sesame cultivars, including C1 (Darab 1), C2 (local Fasa), C3 (Iraqi), C4 (Takpar Dashtestan), and C5 (Sheshpar Borazjan). Treatments with foliar application of sulfur at concentrations of 6 and 8 mg/L were statistically superior to other treatments in terms of SY and OY with no statistically significant differences. The highest SY belonged to C1, C4, and C5, and the highest OY was recorded in C4. Interaction of C5 and C4 with foliar application of sulfur at 8 mg/L led to the highest SY and OY, respectively, among the experimental treatments. There was a significant positive correlation (r = 0.85**) between SY and OY. A total of 11 fatty acids, including four saturated fatty acids (SFAs: myristic, palmitic, margaric, and stearic acids) and seven unsaturated fatty acids (UFAs: palmitoleic, ginkgolic, oleic, linoleic, α-linoleic, arachidonic, and gadoleic acids) were isolated from the tested sesame cultivars. The results indicated different behaviors of genotypes in terms of fatty acid content. Oleic acid (44.5%) and linoleic acid (36.8%) were the most UFAs in the sesame cultivars. With increasing sulfur levels, all fatty acids, except linoleic acid, increased in sesame seeds. Among the studied fatty acids, the highest rate of increase belonged to arachidonic acid, which increased by 17.2% with rising concentrations of sulfur spraying compared to the control without foliar application. SY and OY had a significant positive relationship with linoleic acid (r = −0.79) at a probability level of 5%. There were significant negative correlations between SY and oleic and stearic acids (r = −0.75 and r = −0.85, respectively) at a probability level of 5%.

Keywords; Sesame cultivars, Oil yield, Fatty acids.

Introduction

According to the FAO, the area under sesame cultivation has increased worldwide over the past 20 years and reached about 9.99 million hectares in 2017, with a production of about 5.5 million tons. In the same year (2017-18), the area under cultivation and estimated sesame production were 30017 ha and 30649 tons, respectively, in Iran. The southern region of Kerman province and Fars and Khuzestan provinces cover the highest area under cultivation of sesame (FAO, 2018).

Sesame, *Sesamumn indicum*, is one of the oldest oilseeds used by humans, which was first cultivated in Africa and shortly reached India. It is an annual plant with white, pink or purple flowers that grows to a height of 1-2 m. The fruit of this plant is in the form of capsules containing white, yellow, gray seeds, red, brown, and black sesame seeds (Vaughan and Geissler, 2009). Sesame seeds contain a high level of oil (42-56%) and protein (20-25%) and is a good source of minerals, in particular calcium, phosphorus, potassium, and iron (Desphande et al., 1996). In the vast majority of the literature, the major fatty acids in sesame are linoleic acid (40.5-47.9%), oleic acid (35.9-42.3%), palmitic acid (7.9-12%), and stearic acid (4.8-6.1%) (Abou-Gharbia et al., 2000; Hwang, 2005; Were et al., 2006). One of the important characteristics of oil plants is the type and content of fatty acids therein, and the ratios of these substances in the oil composition of the plant are very important in the nutritional and economic value of oil (Dogan and Akgul, 2005). The ratio of monounsaturated fatty acids, such as oleic acid, causes more durability and stability of oil against oxidation and the possibility of longer storage. Polyunsaturated fatty acids (PUFAs), on the other hand, such as linoleic acid and linolenic acid, though being more sensitive to oxidation, are important in terms of human nutrition and health (Veatankchalam and Sathe). Previous research on the percentages of fatty acids in sesame indicate a high variation in the ratios of saturated and unsaturated fatty acid contents (Elleuch et al., 2007). Many researchers generally believe that plant genetic behaviors, or preferably the cultivar, play a more important role than environmental conditions in fatty acid content (Pavan Kumar and Neelakantan, 2020; Das and Samanta 1998; Deepkumar et al. 2019; El Habbasha et al., 2007).

The supply of adequate amount of nutrients needed by plants in soil using chemical fertilizers is one of the most important aspects of crop management to increase production and improve the quality of crops (Tehrani et al., 2012). Sulfur is the fourth essential element after nitrogen, phosphorus, potassium. In plants, it is mainly involved in the synthesis of sulfur-containing amino acids (e.g. methionine and cysteine), formation of chlorophyll, activation of protein-degrading enzymes, participation in the structure of biotin vitamins, and activation of ATP sulfurylase (Jez, 2004; Mohammadi, 2009). Sulfur is also a constituent of coenzyme A (CoA), which is formed when sulfur is combined with acetic acid, and is important in fat metabolism (Walter Heldt and Piechulla, 2011). Sulfur consumption in glycolysis path, isolation of carboxyl group from pyruvate, and formation of Acetyl-CoA are catalyzed by a multi-enzyme system, with the involvement of three sulfur coenzymes, namely thiamine pyrophosphate, the sulfhydryl-disulfide-lipoic acid redox system, and sulfhydryl CoA. Therefore, the CoA acetyl group is displaced to the Krebs cycle or to the fatty acid synthesis pathway. For the synthesis of long-chain fatty acids, binding double-carbon units require temporary use of carboxyl group. This is carried out by biotin, a sulfur-containing coenzyme, and increases oleic acid content in the seed, resulting from sulfur availability at the seed filling stage and prevents the conversion and reduction of oleic acid into erucic acid (Jan et al., 2002). Seed yield and its components, oil percentage, and oil yield increased significantly in different sesame cultivars using 50 kg/ha of sulfur (Raza et al., 2018).

Sulfur requirements of oilseeds are higher than those of root crops, cereals, and seeds (Motowicka-Terelak and Terelak 2000; Pedro A. S. 2019). Due to the reduction of sulfur emissions to the atmosphere and the use of sulfur-free mineral fertilizers, this element was observed to be deficient in agricultural products, in particular oilseeds (Schnug and Haneklaus 1998; Stern 2005; Awulachew, M.T., 2019). Sulfur is absorbed as sulfate through the root system of plants and is then transferred to chloroplasts of leaf cells, where it is reduced to sulfide and eventually converted into organic compounds (Fuentes-Lara, 2019). There are reports on the use of sulfur to improve SY and related components (Raja et al. 2007), oil content (Shah et al., 2013), and seed protein content (Raza et al.2018) in sesame. Reduction of sulfur input results in sulfur deficiency in the plant, delayed ripening of crops, and ultimately decreased plant height and quality (Hawkesford, 2000). Sulfur is an important component of various plant proteins and plays an essential role in root growth and seed production. This element is a basic constituent of several amino acids (cysteine, cysteine, and methionine), which are the basic structural units of protein molecules and are responsible for the development of flavor and odor in oilseeds (Zhao et al., 1999). Sulfur application was observed to increase seed oil and protein contents (Malhi et al., 2007).

The first report on foliar uptake of nutrients was published in 1844, after which Mayer and Bohm reviewed previous results. At the horticultural department of the University of Michigan, Wittwer and Lundahl (1951) examined the transport of phosphorus and potassium radioactive isotopes. According to their findings, plants are able to absorb nutrients through leaves and shoots, and nutrients are transported about 30 cm in plant organs within an hour in some plant genera. They also found a success rate of about 95% in nutrient uptake through foliar feeding, but it varied considerably (about 10%) in the root uptake depending on the physicochemical conditions of the soil. Soil pH is one of the limiting factors of nutrient uptake because elements can only be absorbed by plants at a certain pH range. Since most of agricultural soils are alkaline in Iran, there are always several problems, such as the fixation of elements, in the uptake and translocation of elements, for which using foliar application is the only effective method to compensate for nutrient deficiency (Leahu et al., 2012).

Under conditions of biotic and abiotic environmental stresses, such as frostbite, high temperatures, salinity, drought, pruning, pesticide use, etc., the plant loses the ability to uptake nutrients through roots due to decreased root activity, and foliar feeding is the most effective method. Plant nutrition through roots travels a long route in the plant to reach the leaves and fruits, but in spraying, the nutrients required by the plant are rapidly enter the plant phloem and reach the target organs. In fact, foliar application is a shortcut for plant nutrition (Phillips and Mullins, 2004).

Foliar application is highly efficient for elements with low mobility in soil (phosphorus, potassium, and calcium) and trace elements (calcium, magnesium, sulfur, boron, iron, manganese, and zinc) in plants because a deficiency of these elements is always observed in plants (Kinaci and Gulmezoglu, 2007; Fernández and Brown, 2013).

The use of sulfur fertilizers may improve the yield and quality of agricultural products (Wilson et al., 2020). Foliar application of sulfur increases SY and the polymerization content of seed protein, which in turn significantly improves the mixing properties of dough (Tea et al., 2004). In oil plants, the use of sulfur causes significant changes in the oil content and its compounds (Malhi, 2007). In recent years, sulfur is one of the main limiting elements for the production of oilseeds due to its widespread shortage (Singh, 2000).

However, for reasons such as low yield, susceptibility to diseases, unlimited growth, and flowering of capsules, less attention has been paid to sesame than other crops, and has even become a forgotten plant. Endemic masses are of particular importance because they have been able to maintain their survival over long years and are well adapted to the climatic conditions of that region; if they have appropriate traits, they can be used as a valuable genetic resource in the improvement of new cultivars (Baydar et al., 1999).

One of the most important methods for increasing agricultural production in crop management programs is to increase fertilizer use efficiency. To achieve this goal, optimum amounts of fertilizer application should be considered for each crop based on the plant nutritional needs during growth season and the content of nutrients in soil and plants. Morphological and physiological characteristics of plants are often influenced by their access to fertilizer sources, in particular microelements. Considering the effect of sulfur fertilizer on the quality characteristics of oil products and higher foliar application efficiency of elements than the soil method of fertilizer use, this study aimed to investigate the effect of foliar application of sulfur fertilizer at different levels on quantitative and qualitative characteristics and efficiency of sulfur consumption in sesame plant.

Materials and Methods

This study was conducted as a factorial experiment based on a randomized complete block design with two factors and three replications in a farm located in rural farms of Fasa city (53.63° E, 29.09° N, and an altitude of 1450 m) during 2018 and 2019. Before land preparation, the farm soil was sampled by an auger at 0-15 and 15-30 cm depths to determine the physicochemical properties of the soil. Experimental treatments consisted of foliar application of sulfur at concentrations of zero (spraying with pure water) and 1, 2, 4, and 8 mg/L (spraying with liquid sulfur). Sulfur was sprayed by a portable sprayer with a calibration of 300 l/ha, and thus liquid sulfur was used at 0, 300, 600, 1200, and 2400 ml ha^{-1}.The sesame cultivars were Darab1(C1), local Fasa (C2), Iraqi (C3), Takpar Dashtestan (C4) and Sheshpar Borazjan (C5).

Each plot consisted of six planting lines with a distance of 75 cm and a length of 6 m, and 150 kg ha^{-1} of pure nitrogen was used from urea source in all plots. All sesame cultivation operations were performed based on conventional methods. After ripening, the margin was removed, sesame crop was harvested by hand, and SY ha^{-1} was calculated based on 12% moisture content. The effects of experimental treatments were investigated on seed and oil yields as well as of fatty acid compositions of seeds.

Oil percentage was measured by the Soxhlet method. To determine the composition of fatty acids, methyl ester fatty acids were first prepared according to the National Standard of Iran (No. 4090, 1997). Fatty acids in the samples were then analyzed by a gas chromatograph (Techcomp, China) equipped with flame ionization detector according to the AOAC method no. 963.22 (AOAC, 2003). Seed oil percentage was multiplied by seed yield to calculate oil yield.

Data were analyzed by analysis of variance (ANOVA) using SAS statistical program and the obtained averages were compared with the Duncan's test at a probability level of 5%.

Results and Discussion

According to meteorological statistics, the maximum temperatures in the studied months were recorded in August (40.3 and 41 °C in 2018 and 2019, respectively) and the minimum belonged to November (9 and 7.9 °C in 2018 and 2019, respectively). Total rainfall levels in the entire growing period were 11.9 and 31.7 mm in 2018 and 2019, respectively, all of which occurred in November and rainfall was zero in other crop growing months.

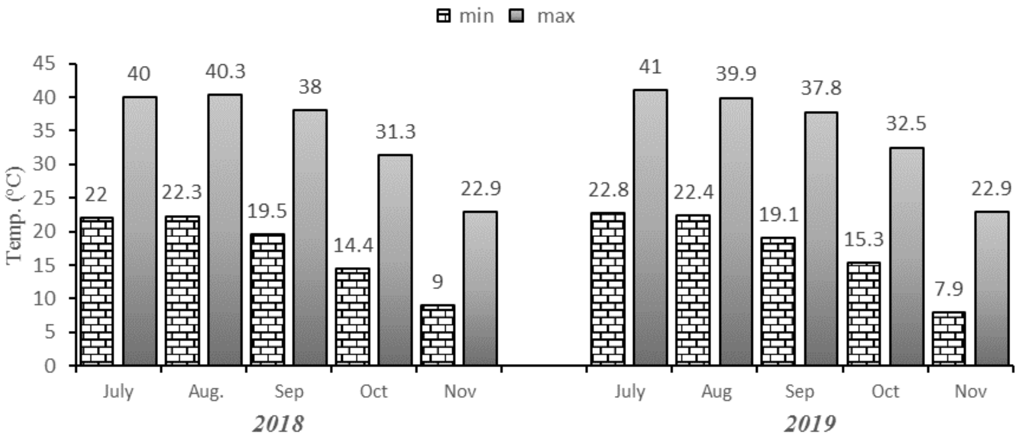


Figure 1. Average, minimum, and maximum temperatures in the studied months

The results of physicochemical analysis of the studied field soil in the experimental years (Table 1) showed that the field soil was without salinity with alkaline acidity, low organic carbon, medium to good phosphorus and potassium, suitable micronutrients of iron, zinc, manganese, and copper, and a loamy soil texture. Based on these results, potash and phosphorus fertilizers and foliar application of micronutrients were not necessary due to appropriate levels of these elements.

Table 1. Results of physicochemical analysis of the experimental farm soil before the experiment

Year	EC	pH	OC	N	P	K	Fe	Zn	Mn	Cu	SAND	SILT	CLAY
	dS.m^{-1}	%			PPM						%		
2018	2.5	7.52	0.44	0.02	15.4	449	7.2	1.53	19.75	1.52	31.6	45.1	23.3
2019	3	7.6	0.46	0.01	13.4	438	7.1	1.4	19.8	1.50	33	43.2	23.8

The results of ANOVA revealed no significant changes in seed and oil yields in the two years and the effect of year alone and its interaction with the studied factors were not significant on seed and oil yields. This means that different cultivars showed similar reactions in conditions of the two years and the mean changes of most traits in the second experimental year were non-significant compared to the first year. This can be attributed to the lack of a considerable difference in the temperature, particularly at the beginning of the growing season in the two experimental years and relatively similar soil conditions, leading to uniform germination and suitable establishment of seedlings in both years, as well as ideal conditions for a good high-yielding farm by performing appropriate photosynthesis. According to the results of ANOVA, sulfur had a significant effect on seed and oil yields. Several researchers have reported that different sesame cultivars and species respond differently to sulfur fertilizer in terms of different traits, such as yield components, oil concentration, and seed protein (Sing et al., 2007; Thanunathan et al., 2002).

Table 2. Summary of combined ANOVA for seed yield (G.Y) and oil yield (O.Y) in sesame cultivars at different sulfur spraying levels

S.O.V.		Mean of squares	
	df	G.Y.	O.Y.
Year(Y)	1	1130757.71 ^{ns}	222049.77^{ns}
Rep× Y	4	7068460.01 ^{ns}	1001230.86^{ns}
Cultivar(C)	4	5760789.05**	2330222.90**
C×Y	4	106854.78 ^{ns}	51537.50^{ns}
Sulfur rate(S)	4	3963420.04**	1167791.80**
S×Y	4	13035.80 ^{ns}	1533.69^{ns}
C× S	16	96362.94**	14616.46**
C×S×Y	16	4180.53 ^{ns}	628.36^{ns}

Error	96	46812.58	9581.13
CV (%)		10.9	

**: Significant at a probability level of 1%; ns: non-significant

SY and OY

Crop yield in different cultivars was compared by many researchers and it was found that plant characteristics depended on the cultivar and its genetics. Cultivars with high genetic characteristics of seed production and yield per unit area are more successful in this regard (Deepkumar et al., 2019). Anastasi et al. (2015) reported that different sesame cultivars were different significantly in SY, OY, and protein content.

Comparison of mean SY showed that the cultivars Sheshpar Borazjan, Takpar Dashtestan, and Darab 1 had the highest SY, respectively, relative to the other ones with no significant differences with each other, which could be due to genetic differences of the cultivars in using growth resources to increase SY per unit area. In this study, Takpar Dashtestan, with an average of 1212.2 kg/ha of oil, was superior to Sheshpar Borazjan and Darab 1 cultivars (Fig. 2).

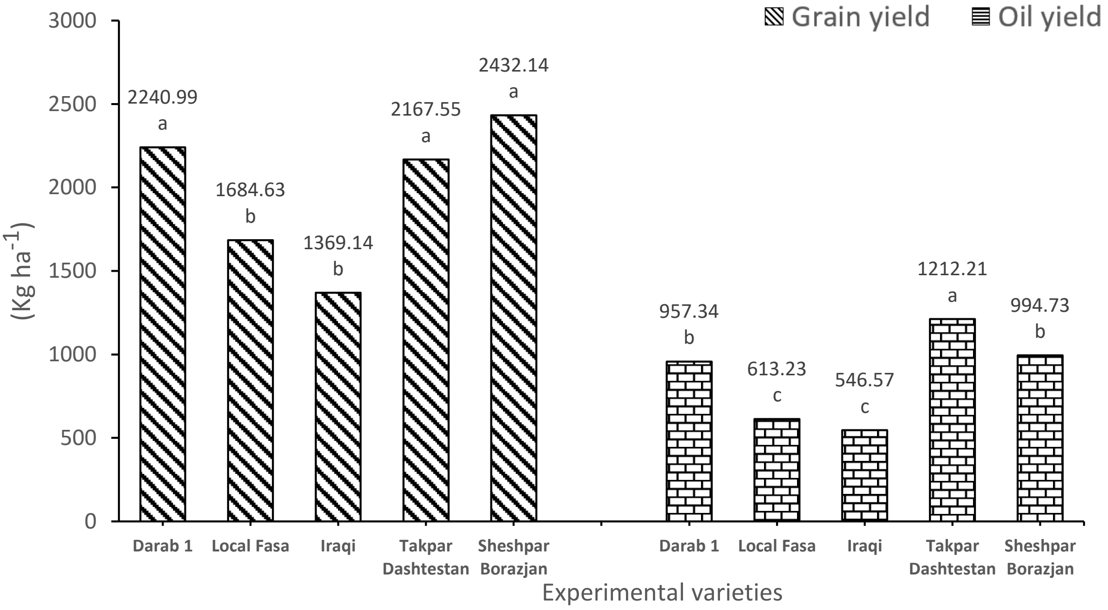


Figure 2. Seed yield and oil yield in the studied cultivars. Averages with at least one similar letter in each chart have no statistically significant differences (Duncan 5%).

In this experiment, SY and OY had no significant changes by foliar application of sulfur up to 2 mg/L, and then these traits increased significantly by sulfur spraying at concentrations of 4 and 8 mg/L (Fig. 3). The yield of Iraqi cultivar did not increase significantly up to a foliar application level of 1 mg/L, and then changes in SY and OY increased significantly. In the other cultivars, this yield stability was up to 2 mg/L foliar application of liquid sulfur. In all the cultivars, the increase in SY and OY was not significant with foliar application of sulfur more than 4 mg/L, suggesting differences in physiological requirements of different sesame cultivars to sulfur or more ability of Iraqi cultivar in the uptake of growth resources to increase the yield. In this regard, application of suitable sulfur levels was shown to change the resource use efficiency by the crop to increase the yield (Kramer et al., 2002).

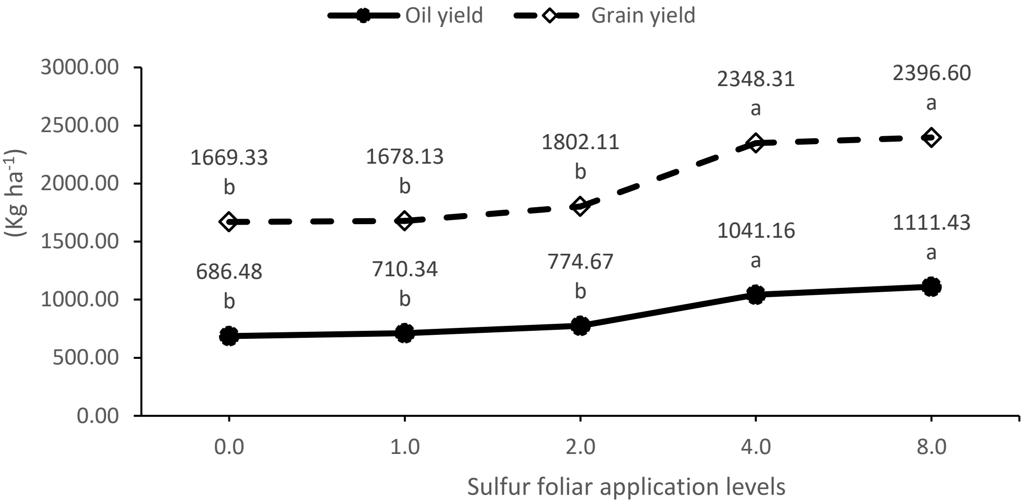
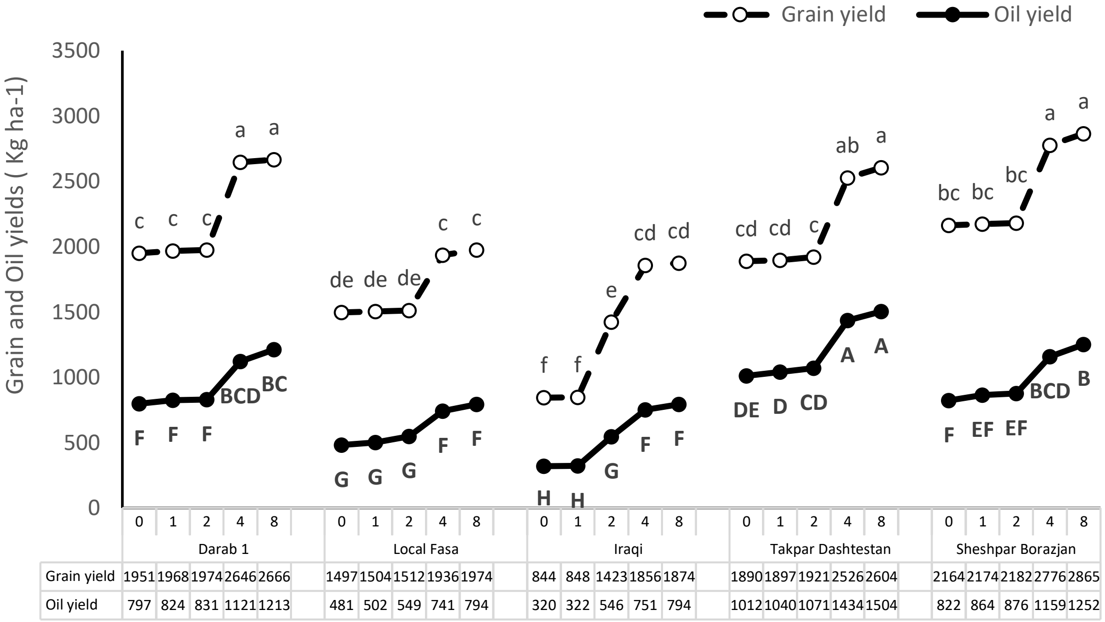


Figure 3. Changes in seed yield and oil yield at different concentrations of sulfur foliar application. There are no statistically significant differences between the averages with at least one similar letter per chart (Duncan 5%).

Among the studied cultivars, the highest average SY (2865 kg ha^{-1}) belonged to Seshpar Borazjan, and Takpar Dashtestan contained the highest average OY (1504 kg ha^{-1}). Comparison of changes in SY and OY with increasing sulfur levels indicated the highest ability of sulfur fertilization in Iraqi cultivar, so that foliar application of liquid sulfur by 8 mg/L increased these two indices by 1.2 and 1.5 times, respectively. Despite the highest OY and the increased percentage of OY ha^{-1} in Takpar Dashtestan cultivar, foliar application of 8 mg/L liquid sulfur increased OY by 48.6%, which was the lowest increase among the studied cultivars. Thus, it seems that the high OY in this cultivar was more affected by the plant genetic potential than the other cultivars. The highest and lowest changes in SY belonged to Iraqi and local Fasa with foliar application of liquid sulfur at 8 mg/L (Fig. 4).



	0	1	2	4	8	0	1	2	4	8	0	1	2	4	8	0	1	2	4	8	0	1	2	4	8
	Darab 1					Local Fasa					Iraqi					Takpar Dashtestan					Sheshpar Borazjan				
Grain yield	1951	1968	1974	2646	2666	1497	1504	1512	1936	1974	844	848	1423	1856	1874	1890	1897	1921	2526	2604	2164	2174	2182	2776	2865
Oil yield	797	824	831	1121	1213	481	502	549	741	794	320	322	546	751	794	1012	1040	1071	1434	1504	822	864	876	1159	1252

Figure 4. Comparison of the effect of foliar application of sulfur on seed and oil yields of the studied sesame cultivars. Averages with at least one similar letter in each curve have no statistically significant differences (Duncan 5%).

Fatty acids in seed oil

Oil content and fatty acid compositions in oilseed crops are influenced by the genotype, location, temperature, moisture content, growth conditions, sowing date, fertilization, and interaction of these factors. In total, 11 fatty acids including four SFAs (myristic, palmitic, margaric, and stearic acids) and seven PUFAs (palmitoleic, ginkgolic, oleic, linoleic, alpha-linoleic, arachidonic, and gadoleic acids) were isolated from the experimental sesame cultivars. The results showed different behaviors of genotypes in terms of fatty acid levels (Table 3). Oleic (44.5%) and linoleic (36.8%) UFAs were most abundant in sesame cultivars. A higher level of oleic acid in the oil composition is an advantage of sesame because oleic acid is one of the essential fatty acids. Palmitic and stearic acids (9.6 and 7.2%, respectively) had the highest average concentrations among SFAs. The low level of palmitic acid in the oil fatty acid profile is necessary in terms of nutritional health. Palmitic acid content in sesame oil should be between 7.9 and 12% of fatty acids and above 12% is impermissible due to significant harms of palmitic acid in sesame oil according to the international Codedex standard (FAO/WHO and Codex Alimentarius Commission, 2001). Margaric, palmitoleic, ginkgolic, and gadoleic acids were not observed in Iraqi cultivar, and Darab 1 did not contain the PUFA palmitoleic acid. Changes in fatty acid profile are influenced by genetics, the environment, and their interaction (Carlsson et al., 2008).

Table 3. Summary of two-year combined ANOVA for fatty acid composition of sesame cultivars at different concentrations of sulfur foliar application

		Myristic	Palmitic	Margaric	Stearic	Palmitoleic	Ginkgolic	Oleic	Linoleic	α-linoleic	Arachidonic	Gadoleic
S.O.V.	df	c14:0	c16:0	c17:0	c18:0	c16:1	c17:1	c18:1	c18:2	c18:3	c20:0	c20:1
Year (Y)	1	0.022^{ns}	138.1 ^{ns}	0.009 ^{ns}	77.73 ^{ns}	0.016 ^{ns}	0.01 ^{ns}	2958.5 ^{ns}	2035.2 ^{ns}	0.74 ^{ns}	0.14 ^{ns}	0.03 ^{ns}
Rep× Y	4	0.001 ^{ns}	23.26 ^{ns}	0.002 ^{ns}	13.09 ^{ns}	0.0028 ^{ns}	0.003 ^{ns}	498.02 ^{ns}	342.61 ^{ns}	0.125 ^{ns}	0.023 ^{ns}	0.006 ^{ns}
Cultivar(C)	4	0.117**	21.439**	0.067**	10.56**	0.3528**	0.055**	37.54**	127.72**	0.877**	0.032**	0.223**
C×Y	4	0.001 ^{ns}	0.214 ^{ns}	0.001 ^{ns}	0.11 ^{ns}	0.0035 ^{ns}	0.001 ^{ns}	0.37 ^{ns}	1.28 ^{ns}	0.009 ^{ns}	0.000 ^{ns}	0.002 ^{ns}
Sulfur rate (S)	4	0.001 ^{ns}	0.515**	0.001**	0.02**	0.0001**	0.001**	0.65**	22.70**	0.007**	0.010**	0.001**
S×Y	4	0.001 ^{ns}	0.005 ^{ns}	0.001 ^{ns}	0.00 ^{ns}	0.0001 ^{ns}	0.001 ^{ns}	0.006 ^{ns}	0.23 ^{ns}	0.001 ^{ns}	0.001 ^{ns}	0.001 ^{ns}
C× S	16	0.001 ^{ns}	0.250 **	0.001**	0.01**	0.0001**	0.002**	0.34**	22.54**	0.003**	0.002**	0.001**
C×S×Y	16	0.002 ^{ns}	0.002 ^{ns}	0.001 ^{ns}	0.00 ^{ns}	0.0001 ^{ns}	0.002 ^{ns}	0.003 ^{ns}	0.23 ^{ns}	0.001 ^{ns}	0.001 ^{ns}	0.001 ^{ns}
Error	96	0.001	0.006	0.001	0.00	0.0001	0.002	0.01	0.07	0.001	0.001	0.001
CV (%)		19.2	8.3	5.7	3.7	9.5	10.3	5.2	5.7	12.2	12.1	5.3

* and **: Significant at 5% and 1% probability levels, respectively. ns: Non-significant

Table 4. Classification of fatty acids isolated from sesame cultivars

Fatty acid		Classification	Darab 1	Local Fasa	Iraqi	Takpar Dashtestan	Sheshpar Borazjan
Myristic	c14:0	SFA	0.12	0.03	0.1	0.188	0.17
Palmitic	c16:0	SFA	10.596	9.266	9.584	10.148	8.394
Margaric	c17:0	SFA	0.128	0.09	0	0.08	0.09
Stearic	c18:0	SFA	6.848	7.248	7.994	7.466	6.438
Palmitoleic	c16:1	UFA	0	0.15	0	0.118	0.256
Ginkgolic	c17:1	UFA	0.104	0.04	0	0.036	0.05
Oleic	c18:1	UFA	42.958	45.332	44.778	45.468	43.52
Linoleic	c18:2	UFA	38.026	36.43	34.792	35.176	39.754
α-linoleic	c18:3	UFA	0.734	0.858	0.422	0.816	0.688
Arachidonic	c20:0	UFA	0.3	0.33	0.292	0.256	0.338
Gadoleic	c20:1	UFA	0.15	0.18	0	0.216	0.194

As shown by the results of ANOVA (Table 3), that the percentage of changes in oil fatty acids in different sesame cultivars was not affected by the experimental years. Besides, the effect of year and cultivar, foliar application of sulfur, and their interaction had no significant effects on the fatty acid content. These results were influenced by uniform planting, soil, and climatic conditions in the two experimental years (Fig. 1 and Table 1). The results of ANOVA showed that myristic and ginkgolic acids of sesame seed fatty acids were not significantly affected by foliar application of sulfur. However, all five sesame cultivars were significantly different in the percentages of these fatty acids. The cultivar and foliar application of sulfur influenced significantly the presence of other fatty acids in sesame oil composition, which is similar to those reported by other researchers (Jan et al., 2002; Grant et al., 2003; Malhi, and Gill, 2002; Malhi et al., 2007).

Among the identified fatty acids, oleic acid had the highest level. The presence of such a high oleic acid content, which is highly resistant to oxidation of PUFAs (linoleic and linolenic acids), renders the oil a good stability to heat. In addition, oleic acid is effective in the prevention of coronary artery occlusion and cardiovascular diseases by reducing bad blood cholesterol (low-density lipoprotein, LDL) and maintaining or increasing good cholesterol (high-density lipoprotein, HDL). Darab 1 cultivar contained the utmost contents of palmitic and ginkgolic acids compared with the other cultivars. Myristic, oleic, and α-linoleic fatty acids in local Fasa, stearic acid in Iraqi, oleic and gadoleic acids in Takpar Dashtestan, and margaric, palmitoleic, linoleic, and arachidonic acids in Sheshpar Borazjan were the most abundant fatty acids compared to the other cultivars.

Sulfur plays an important role in the seed chemical composition and increases its oil and fatty acid percentages (Raza et al., 2018). This element is one of the structural components of cysteine and methionine amino acids and has an essential role in the synthesis of proteins and enzymes. Therefore, insufficiency of sulfur can affect the yield and quality of oilseed crop (Scherer, 2001). All fatty acids, except linoleic acid, increased in seeds with increasing sulfur levels. Among the studied fatty acids, the highest rate of increase belonged to arachidonic acid, which increased by 17.2% with rising concentrations of sulfur spraying compared with the control without foliar application. After this fatty acid, the uppermost rates of increase were recorded for α-linoleic, gadoleic, and palmitic acids in comparison to the control without sulfur spraying.

Foliar application of liquid sulfur at a concentration of 8 ml/L resulted decreased linoleic acid levels by 1.23, 1.79, 2.33, and 3.72%, respectively. Increasing sulfur levels in sunflower reduced linoleic acid content (Krishnamurthi, and Mathan, 1996). However, some reports also indicate an increase in this fatty acid as a result of increasing sulfur concentrations (Raza et al., 2017). Increasing sulfur foliar application up to 4 mg/L had no significant effect on arachidonic and α-linoleic acids and then these fatty acids increased significantly. Among the studied fatty acids, palmitic and palmitoleic acid showed the highest significant response to changes in lower concentrations of sulfur foliar application. These two fatty acids increased significantly (2.4% and 1.96%, respectively) in sesame seeds by spraying 1 ml/L of liquid sulfur.

Table 5. Effects of sesame cultivars and concentrations of sulfur foliar application on sesame fatty acids

	Myristic	Palmitic	Margaric	Stearic	Palmitoleic	Ginkgolic	Oleic	Linoleic	α-linoleic	Arachidonic	Gadoleic
Treatments	c14:0	c16:0	c17:0	c18:0	c16:1	c17:1	c18:1	c18:2	c18:3	c20:0	c20:1
Cultivar											
C1	0.12ab	10.60a	0.13d	6.85d	0.00d	0.10a	42.96d	38.03b	0.73c	0.30c	0.15d
C2	0.03a	9.27d	0.09b	7.25c	0.15b	0.04c	45.33a	36.43c	0.86a	0.33b	0.18c
C3	0.10c	9.58c	0.00d	7.99a	0.00d	0.00d	44.78b	34.79d	0.42e	0.29d	0.00e
C4	0.19d	10.15b	0.08c	7.47b	0.12c	0.04c	45.47a	35.18d	0.82b	0.26e	0.22a
C5	0.17bc	8.39e	0.09a	6.44e	0.26a	0.05b	43.52c	39.75a	0.69d	0.34a	0.19b
Sulfur rate(ml.lit-1)											
S1		9.32d	0.072b	7.148b	0.102c		44.1d	35.1a	0.69b	0.29b	0.146c
S2		9.55c	0.074b	7.178ab	0.104b		44.3cd	37.0b	0.69b	0.29b	0.146c
S3		9.62bc	0.074b	7.198ab	0.106a		44.4bc	37.2b	0.70b	0.30b	0.146b
S4		9.70ab	0.084a	7.21ab	0.106a		44.5b	37.4b	0.70b	0.30b	0.148b
S5		9.80a	0.084a	7.26a	0.106a		44.8a	37.5c	0.73a	0.34a	0.154a

Averages with at least one similar letter have no statistically significant difference (Duncan 5%). Cultivars are C1: Darab 1, C2: Local Fasa, C3: Iraqi C4: Takpar Dashtestan, and C5: Sheshpar Borazjan. Foliar application of liquid sulfur at 0 (S1), 2 (S2), 4 (S3), 6 (S4), and 8 (S5) ml/L.

Interactions between foliar application of sulfur and cultivars were not significant on myristic and palmitoleic acids. In Darab 1, margaric acid rose by 60% with increasing foliar application levels from 0 to 8 mg/L. The highest increases were recorded for palmitic acid (1.53%) in local Fasa, palmitic acid (6.24%) in Iraqi, arachidonic acid (47.83) in Takpar Dashtestan, and arachidonic acid

(18.75) in Sheshpar Borazjan. Linoleic acid changes had a downward trend of in all the cultivars, and the highest reduction belonged to local Fasa with sulfur foliar application at 8 mg/L.

Correlations between seed and oil yields and the seed fatty acid content showed the highest positive correlation between SY and all fatty acids, except oleic and stearic acids. There was a negative correlation between these two fatty acid contents and decreased with increasing SY.

Table 6. Comparison of average interactions of sesame cultivars and concentrations of sulfur foliar application

Treatment		Palmitic		Margaric		Stearic		Ginkgolic		Oleic		Linoleic		α-linoleic		Arachidonic		Gadoleic	
C1	s1	10.38	de	0.10	c	6.79	g	0.10	a	42.63	l	38.90	d	0.72	f	0.29	f	0.15	f
C1	s2	10.51	cd	0.11	b	6.81	g	0.10	a	42.70	l	38.05	e	0.73	f	0.29	f	0.15	f
C1	s3	10.58	bc	0.11	b	6.85	fg	0.10	a	42.98	k	38.00	e	0.73	f	0.29	f	0.15	f
C1	s4	10.67	b	0.16	a	6.88	fg	0.11	a	43.15	k	37.92	e	0.73	f	0.29	f	0.15	f
C1	s5	10.84	a	0.16	a	6.91	f	0.11	a	43.33	j	37.67	e	0.76	e	0.34	b	0.15	f
C2	s1	9.17	k	0.09	d	7.21	e	0.04	bc	45.13	e	40.24	b	0.85	b	0.33	c	0.18	e
C2	s2	9.27	k	0.09	d	7.24	e	0.04	bc	45.28	cde	37.06	f	0.86	b	0.33	c	0.18	e
C2	s3	9.28	k	0.09	d	7.26	e	0.04	bc	45.40	bc	36.55	gh	0.86	b	0.33	c	0.18	e
C2	s4	9.30	jk	0.09	d	7.26	e	0.04	bc	45.41	bc	36.06	ij	0.86	b	0.33	c	0.18	e
C2	s5	9.31	jk	0.09	d	7.27	e	0.04	bc	45.44	bc	35.37	kl	0.86	b	0.33	c	0.18	e
C3	s1	9.29	jk	0.00	f	7.92	b	0.00	d	44.39	g	36.40	ghi	0.42	i	0.29	f	0.00	g
C3	s2	9.43	ij	0.00	f	7.97	b	0.00	d	44.62	f	36.38	ghi	0.42	i	0.29	f	0.00	g
C3	s3	9.61	h	0.00	f	7.98	b	0.00	d	44.69	f	36.74	fg	0.42	i	0.29	f	0.00	g
C3	s4	9.72	h	0.00	f	7.99	b	0.00	d	44.77	f	36.83	fg	0.42	i	0.29	f	0.00	g
C3	s5	9.87	g	0.00	f	8.11	a	0.00	d	45.42	bc	36.14	hi	0.43	i	0.30	e	0.00	g
C4	s1	9.47	i	0.08	e	7.41	d	0.03	c	45.17	de	37.97	e	0.78	de	0.23	h	0.21	b
C4	s2	10.21	f	0.08	e	7.45	cd	0.03	c	45.32	bcd	35.64	jk	0.78	de	0.23	h	0.21	b
C4	s3	10.24	f	0.08	e	7.46	cd	0.04	bc	45.45	bc	35.17	l	0.80	cd	0.24	g	0.21	b
C4	s4	10.32	ef	0.08	e	7.47	cd	0.04	bc	45.51	b	34.95	lm	0.81	c	0.24	g	0.21	b
C4	s5	10.50	cd	0.08	e	7.54	c	0.04	bc	45.89	a	34.48	m	0.91	a	0.34	b	0.24	a
C5	s1	8.27	m	0.09	d	6.41	h	0.05	b	43.41	ij	42.08	a	0.67	h	0.32	d	0.19	d
C5	s2	8.31	m	0.09	d	6.42	h	0.05	b	43.47	ij	40.29	b	0.68	h	0.33	c	0.19	d
C5	s3	8.41	lm	0.09	d	6.44	h	0.05	b	43.48	ij	39.88	bc	0.69	gh	0.33	c	0.19	d
C5	s4	8.48	l	0.09	d	6.45	h	0.05	b	43.56	hi	39.56	c	0.69	gh	0.33	c	0.20	c
C5	s5	8.50	l	0.09	d	6.47	h	0.05	b	43.68	h	39.01	d	0.71	fg	0.38	a	0.20	c

Correlations between the studied components

Relationships between different traits generally result from the presence of related genes and the epistemological effect of different genes (Baloch et al., 2014). The results of correlation analysis of oil and fatty acid contents in the studied sesame cultivars are shown in Table 7. Oil yield was positively correlated with myristic ($r = -0.85$), margaric ($r = -0.54$), and gadoleic ($r = -0.72$) acids, but it had significant negative correlations with oleic and stearic acids ($r = -0.69$ and $r = -0.56$, respectively), and was not significantly correlated with the other fatty acids. There were significant negative correlations between SY and oleic and stearic acids ($r = -0.75$ and $r = -0.85$, respectively) at a probability level of 5%. On the other hand, a significant positive relationship was found between seed and oil yields with linoleic acid ($r = -0.79$) at 5% probability level. A similar relationship was reported between OY and oleic acid in sesame seeds (Yol et al., 2015; Were et al., 2006).

Stearic acid had a significant positive relationship with oleic acid, which was also reported by Yol et al. (2015), but it had significant negative relationships with margaric, palmitoleic, ginkgolic, linoleic, arachidonic, and gadoleic acids. There was a significant negative relationship ($r = -0.78$) between oleic acid and arachidonic acid, which was similarly reported by Were et al., 2006). A significant negative relationship was observed between oleic acid and linoleic acid ($r = -0.75$), which was predictable due to the synthesis of the latter from the former (Yol et al., 2015). Given the significant negative relationship between oleic and linoleic acids, it can be concluded that a balance occurred between fatty acid profile and oil percentage so that parallel to the decreasing trend in oleic acid and increasing linoleic acid, which have a balance with each other, OY increased in accordance with these events. These relationships seem logical since the production of each of these compounds is dependent on each other, which is in agreement with Kurt et al. (2018). Similar findings were reported for other oilseed crops, including peanuts (Mora-Escobedo et al., 2015) and soybeans (Farno, 1996).

Research has shown that different enzymatic processes for the synthesis of fatty acids are the main determinants of fatty acid composition in sesame seeds (Were et al., 2006). This inverse relationship between oleic and linoleic acids can be useful in the selection of cultivars in terms of richness in oleic acid or linoleic acid (Pleines and Friedt, 1988; Baydar et al., 1999).

Conclusion

Application of sulfur and its foliar application is one of the important agricultural priorities, particularly in sesame cultivation, and this can have an important contribution to sesame plants to approach potential yield and increase the crop quality and quality. Based on the findings of this study, the use of 8/1000 sulfur solution is recommended to increase sesame seed and oil yields in Fasa region and similar regions. Moreover, Sheshpar Borazjan, Darab 1, and Takpar Dashtestan, with the highest yields among the studied cultivars, are recommended for cultivation in the experimental area and similar conditions. Oleic acid was the major fatty acid found in sesame seeds of Takpar Dashtestan, and its percentage increased with increasing concentrations of sulfur foliar application.

Table 7. Correlations between seed and oil yields and fatty acids of sesame seeds.

	Seed yield	Oil yield	Myristic	Palmitic	Margaric	Stearic	Palmitoleic	Ginkgolic	Oleic	Linoleic	α-linoleic	Arachidonic	Gadoleic
Seed yield	1.00												
Oil yield	0.85**	1.00											
Myristic	0.67*	0.85**	1.00										
Palmitic	0.05ns	0.23ns	0.04ns	1.00									
Margaric	0.76**	0.54*	0.10ns	0.22ns	1.00								
Stearic	-0.85**	-0.56*	-0.26ns	0.34ns	-0.78**	1.00							
Palmitoleic	0.50*	0.31ns	0.25ns	-0.80**	0.25ns	-0.61**	1.00						
Ginkgolic	0.71**	0.49ns	0.14ns	0.40ns	0.93**	-0.71**	-0.04ns	1.00					
Oleic	-0.75**	-0.69**	-0.21ns	-0.03ns	-0.48ns	0.68*	0.07ns	-0.69*	1.00				
Linoleic	0.72**	0.26ns	0.18ns	-0.50*	0.61**	-0.96**	0.60*	0.57*	-0.74**	1.00			
α-linoleic	0.49ns	0.48ns	-0.02ns	0.10ns	0.77**	-0.45ns	0.44ns	0.52*	0.18ns	0.23ns	1.00		
Arachidonic	0.14ns	-0.37ns	-0.41ns	-0.74**	0.25ns	-0.63*	0.57*	0.15ns	-0.78**	0.76**	0.10ns	1.00	
Gadoleic	0.75**	0.72**	0.33ns	-0.06ns	0.77**	-0.63*	0.64*	0.52*	0.03ns	0.42ns	0.92**	0.11ns	1.00

* and **: Significant at 5% and 1% probability levels, respectively. ns: Non-significant.

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