Turkish Journal of Field Crops
field-crops.org

DOI: 10.17557/tjfc.1773975
ISSN: 1301-1111
e-ISSN: 3023-6657
2025, 30(2), 328-338

Effects of Plant Nutrients on Oil Content and Oil Quality of Peanut

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ARTICLE INFO

Research Article
Received: 29 August 2025
Accepted: 24 November 2025
Published: 30 December 2025

Keywords:
Groundnut
Iron
Oil
Selenium
Sulfur

Citation: Sahin, C. B. (2025). Effects of Plant Nutrients on Oil Content and Oil Quality of Peanut. *Turkish Journal of Field Crops*, 30(2), 328-338. https://doi.org/10.17557/tjfc.1773975

ABSTRACT

Plant nutrients are essential for plant physiology, although they are required in small quantities. Along with detecting nutrient shortages, it is crucial to study the varied impacts of nutrients such as iron, sulfur, and selenium. This study specifically investigated the combined effects of iron, sulfur, and selenium fertilizers on the oil content and oil quality factors of peanuts (*Arachis hypogaea* L.). The study was conducted in the Eastern Mediterranean of Türkiye in 2021 and 2022, using a split-split-plot design with three replications. The treatments of Fe (0% and 3%) were assigned to the main plots, S (0, 40, and 60 kg ha−1) to the sub-plots, and Se (0, 20, and 40 ppm) to the sub-sub-plots. Oil content was not significantly affected by the fertilizer treatments, and the maximum values were obtained from the applications of 40 kg sulfur per hectare and 20 ppm selenium. Regarding the Oleic/Linoleic acids ratio, an important indicator of oil quality, the highest values were observed in the treatments of 40 to 60 kg sulfur per hectare and 20 to 40 ppm selenium. In conclusion, iron application had no significant effect, while the application of 40 to 60 kg ha^{-1} sulfur and 20 to 40 ppm selenium could improve the quality of peanut oil, as indicated by a low iodine value (IV) and high oleic acid content and O/L ratio.

1. INTRODUCTION

Peanuts (*Arachis hypogaea* L.), which are grown in a wide area around the world, are a very important source of oil and protein. They belong to the legume family and are annual, summer-growing plants that thrive in warm climates. This plant, which has an important place in the food and agriculture sector, provides producers with significant income (Guvercin & Gok, 2022; Yilmaz et al., 2022). With serious commercial potential in both national and international markets, this plant makes important contributions both as an oil source and as a snack. The high levels of tocopherol in peanut oil, an antioxidant substance, prevent the oil from oxidizing and deteriorating. In Türkiye, it is cultivated in regions influenced by the Mediterranean climate, in light-textured agricultural soils with irrigation (Boydak et al., 2019; Haddadi et al., 2024).

In 1993, 26 million tons of peanuts were produced on 21 million hectares of fields worldwide, while in Türkiye, 70,000 tons were produced on 30,000 hectares of land. By 2023, both worldwide and in Türkiye, the area under cultivation had increased by more than 50%, while production had increased by more than 150%. According to current data, approximately one-third of production took place in China, followed by India and Nigeria with shares of 19% and 8%, respectively. In terms of yield, while there was a 42% increase worldwide over 30 years, Turkey had a 73% increase (FAO, 2025). According to 2023 data, approximately 80% of Türkiye's production took place in the Mediterranean Region, with Adana and Osmaniye standing out with shares of 48% and 24%, respectively (TUIK, 2025)

Plants convert light energy into chemical energy through photosynthesis while continuously absorbing plant nutrients from the soil. Therefore, the nutrients found in the root zone of plants are of vital importance for plant life. In agricultural soils, the rate at which nutrient elements are removed from the soil exceeds the rate at which they are naturally replenished. Therefore, it is necessary to add nutrient elements to the soil, especially in agricultural areas. Otherwise, nutrient deficiency will occur (Turan & Horuz, 2012). Consequently, the process of supplying nutrients to the soil, which we call fertilization, is one of the most important factors in plant nutrition (Sadat Darakeh et al., 2021; Zhou et al., 2021). Although plants require minerals in the soil to be at proper levels, inadequate soil properties or biotic and/or abiotic stress conditions can reduce the roots' ability to take up mineral nutrients. When soil constraints (such as liming, inappropriate pH, and so on) minimize nutrient availability, foliar sprays provide a more efficient solution for plant nutrition (Sahin & Isler, 2021; Zayed et al., 2011).

Iron (Fe) is one of the major plant nutrients that enhances biological nitrogen fixation and nodulation, leading to improved yield. It is also vital for synthesizing protein, DNA, and RNA (Dogan et al., 2007; Guvercin & Gok, 2022). The symptoms of Fe deficiency occur in poor conditions, such as the soil that has a pH higher than 6.5 or calcareous soil, and Fe solubility reaches its minimum. Besides, Fe deficiency affects the biological nitrogen binding and bacterial activity (Chhonkar & Chandel, 1991; Ghasemian et al., 2010). Because of that, leaf chlorophyll content and therefore photosynthesis are affected by deficiency. Accordingly, foliar fertilization is an effective method because it is both fast and economical (Babaeian et al., 2011; Kinaci & Gulmezoglu, 2007; Nasri et al., 2011).

Nano-Selenium applications demonstrate enhanced efficacy by optimizing the biochemical composition of peanuts, reducing oxidative damage, and improving yield parameters (Hussein et al., 2019a; Petkovic et al., 2019). Selenium (Se) alleviates cadmium toxicity in peanut plants, particularly when co-applied with biochar, leading to improved plant growth and increased Se accumulation in seeds (Shao et al., 2022). Additionally, Se supplementation has proven effective in enhancing peanut resilience to environmental stressors, including drought and salinity, thereby promoting better crop performance under adverse conditions. Se biofortification in peanuts not only enhances their antioxidant capacity but also elevates their nutritional value, offering dual benefits for both agricultural productivity and human health (Deliboran et al., 2018; Topuz & Topal, 2021). Moreover, foliar-applied Se is suggested instead of soil application due to greater efficiency. In addition, it reduces the negative effect on the environment (Pezzarossa et al., 2012).

Sulfur (S) is one of the essential micronutrients that has been identified as a key factor in various aspects of plant growth and development by optimizing plant growth, particularly in oil quality (Ariraman & Kalaichelvi, 2020; Brooks et al., 2023; Cannon et al., 2021; Vinothini et al., 2022). This element plays a fundamental role in critical metabolic pathways, including photosynthetic processes, respiratory metabolism, biological nitrogen fixation (Saleem et al., 2023; Sytar et al., 2012), and the biosynthesis of both proteins and lipids, all of which collectively influence plant developmental progression (Erhunmwunse & Farmaha, 2023; Moreira & Moraes, 2016). It mediates structural modifications in oleic acid biosynthesis, resulting in an expanded fatty acid reservoir that ultimately elevates lipid biosynthesis and seed oil content in oilseed crops (Mohammadi & Rokhzadi, 2012; Zhou et al., 2021).

Recent studies have demonstrated the significant physiological impacts of nutrient applications on peanut cultivation. It was reported that Fe supplementation resulted in a marked stimulation of chlorophyll biosynthesis and enhanced vegetative growth during pivotal phenological phases (Kur et al., 2019). Se, along with biochar treatments, mitigated cadmium phytotoxicity while simultaneously promoting biomass accumulation and increasing Se enrichment in seeds, resulting in improved nutritional profiles (Shao et al., 2022). Furthermore, S regulated multiple metabolic processes, including chlorophyll formation and protein anabolism, which collectively determine both quantitative and qualitative parameters of groundnut yield (Vinothini et al., 2022). Toward this end, the present study aimed to determine the effects of Fe, S, and Se and their combination on oil content and oil quality factors of peanut, focusing on their interactions.

2. MATERIALS AND METHODS

Plant material

The study was conducted in Osmaniye, located in the Eastern Mediterranean region of Türkiye, under field conditions, based on the 2021 and 2022 growing seasons. The peanut variety NC-7 (*Arachis hypogaea* L.) was used as the plant material.

Soil properties

The physical and chemical properties of the soil in the experimental area are presented in Table 1. The soil had a clayey-loam texture and exhibited a slightly alkaline reaction throughout the two years (pH: 7.98-8.03). These elevated pH values are consistent with the high lime content observed in the soil (2021: 10.94%; 2022: 8.25%). Regarding nutrient elements, the phosphorus (P) content was at a moderate level, while organic matter (OM) levels (1.02-1.05%) were generally below accepted thresholds and were classified as low. Among the micronutrients, the iron (Fe) content was also measured to be low (1.67-1.91 ppm). The low plant availability of iron was likely constrained by the high soil pH and lime content. Furthermore, a notable decrease in zinc (Zn) content was observed in 2022, dropping from 0.36 ppm to 0.19 ppm (Table 1).

Table 1. Soil characteristics of the experimental area

	pH	O.M. (%)	Lime (%)	P (kg ha^{-1})	K (kg ha^{-1})	Ca (ppm)	Mg (ppm)	Fe (ppm)	Zn (ppm)
2021	7.98	1.05	10.94	92.0	405.6	11,310	450.32	1.67	0.36
2022	8.03	1.02	8.25	93.6	349.1	10,182	445.10	1.91	0.19

O.M.: Organic Matter

Climatic features

The meteorological data, such as total precipitation and average temperature, were presented in Fig. 1. The average temperatures for the experimental and long-term years increased from April to August, then decreased in September. There were no significant differences between the years. In contrast to average temperature, even though there were some fluctuations among months, the total precipitation for the second year of the study was along to long-term values, but higher than the first year (TSMS, 2024).

Experimental design

Certified peanut (*Arachis hypogaea* L. cv. NC-7) cultivar was sown on May 15, 2021, and May 10, 2022, with 70 cm apart rows and 15 cm spacing between plants. Each sub-sub-plot was established with 4 rows and had 5 x 2.8 m = 14 m^2 total area. The experiment had a total of 54 plots. The experimental layout was split-split-plot in a randomized complete block design with three replications. Two Fe-EDTA levels were applied in the main plots as follows: control (0%) and 3%. Three sulfur doses were applied in the sub-plot as follows: control (0), 40 (40S), and 60 (60S) kg per ha, while three selenium treatments were applied in sub-sub-plots as control (0), 20Se, and 40Se ppm. Di-ammonium phosphate (18% N, 46% P_2O_5) was applied at 250 kg ha^{-1} as a bottom fertilizer before sowing. Besides, S (total SO_3 245% w/w and total S 98% w/w) was also given to the soil before sowing, while Fe (water soluble Fe 6% w/w and Fe chelated 6% w/w) and Se (as a commercial water-soluble fertilizer containing 15% selenium) were applied at the R1 (beginning bloom) growth stage as foliar spraying. Post-emergence, manual hoeing was performed, and furrow irrigation was applied. Mature plants were hand-harvested on October 10, 2021, and October 15, 2022.

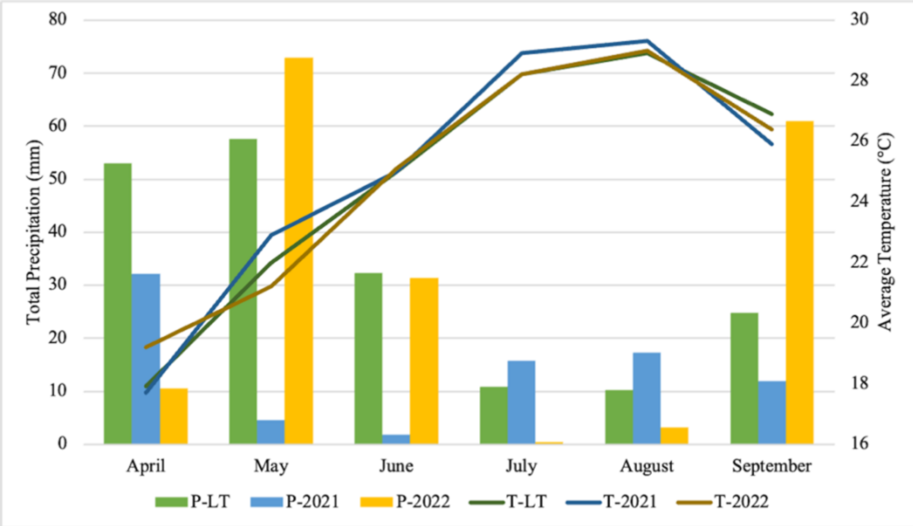

Figure 1. Meteorological data of the studied years and long-term in Osmaniye, Türkiye. (P: Precipitation, T: Temperature, LT: Long-term)

Oil extraction, fatty acid analyses, and oil quality parameters

The traditional Soxhlet method was used for extracting oil from plant material. The apparatus consisted of an extraction chamber, a thimble, and a condenser, with the solvent material being diethyl ether. The fatty acid composition procedure and temperature program were performed according to the method reported in the literature (Sahin et al., 2022). The ratios of oleic and linoleic acids, as well as the iodine values, were calculated using the formulas given below (Chowdhury et al., 2015).

$$\text{Iodine Value (IV)} = (\text{\% oleic acid} \times 0.8601) + (\text{\% linoleic acid} \times 1.7321)$$

$$\text{Oleic Acid/Linoleic Acid (O/L) Ratio} = \frac{\text{\% oleic acid}}{\text{\% linoleic acid}}$$

Statistical analyses

Analysis of variance (ANOVA) was performed for each year, across combined years, and for the mean of years based on a split–split–plot design using IBM SPSS Statistics v27 and RStudio v2024.09.1+394. The figures were generated for the mean of the years regardless of the studied years separately, because there were no significant effects between years. Means were compared using Duncan's multiple-range test (Steel & Torrie, 1980).

3. RESULTS AND DISCUSSION

The investigation into the individual and interactive effects of Fe, S, and Se revealed their significant roles in shaping peanut oil quality. As no significant year effect was observed, data from both years were combined and analyzed according to the split-split-plot design. The detailed ANOVA results are presented in Tables 2 and 3.

Oil content

The oil content was found to be insignificant ($p > 0.05$) for all independent variables and their interactions according to the results of ANOVA (Table 2). The control group for Fe had 49.53±0.12% oil content, while the 3% Fe treatment was 49.33±0.11% (Fig. 2a). The oil content ranged from 49.30±0.16% to 49.50±0.13% for S treatments, and 40S came in first place with its highest value. On the other hand, the oil content varied between 49.28±0.14% and 49.53±0.17 for Se treatments, and the highest value was observed in 20Se treatment. The average value for oil content was 49.43±0.08%. Notably, the combinations of 40S × 0Se and 40S × 20Se without iron application yielded the highest oil content values. Similar to the present study, it was found that oil content was not significantly affected by Fe and S treatments (Bi et al., 2024; Kur et al., 2019). In contrast, oil content was found to be significant in a study conducted with rapeseed (Gironde et al., 2014). The non-significant effect of Fe, S, and Se on oil content can be primarily attributed to the physiological role of these elements and the genetic regulation of oil biosynthesis. Oil accumulation is a genetically strongly programmed process governed by sourcesink relationships. While these nutrients are crucial for overall plant metabolism and stress tolerance, they may not directly regulate the final stages of oil synthesis under the conditions of this study. This finding aligns with studies reporting non-significant effects of Fe and S on peanut oil content (Bi et al., 2024; Kur et al., 2019). Furthermore, the variable impact of Se, which is highly dependent on peanut cultivar and application method (Hussein et al., 2019b; Irmak, 2017), supports the conclusion that the genetic potential of the cultivar used here was likely a determining factor, limiting the effect of mineral applications on oil content (Kumar & Sidhu, 2013).

Table 2. Mean square values for oil content, unsaturated fatty acid compositions, and O/L ratio

SoV	df	Oil content	Oleic acid	Linoleic acid	Linolenic acid	O/L Ratio
Y	1	0.69ns	0.11ns	2.48ns	0.03ns	0.02ns
R (Y)	4	0.22ns	0.41ns	0.80ns	0.01ns	0.01ns
Fe	1	1.07ns	14.77*	9.51**	0.01ns	0.22**
Fe × Y	1	0.23ns	0.06ns	0.03ns	0.01ns	0.01ns
Error 1	4	0.16	1.25	0.08	0.01	0.01
S	2	0.46ns	10.73**	6.85**	0.01ns	0.15**
S × Fe	2	0.83ns	0.03ns	0.02ns	0.01ns	0.01ns
S × Y	2	0.05ns	10.12**	5.37*	0.01ns	0.13**
S × Fe × Y	2	0.19ns	0.01ns	0.01ns	0.01ns	0.01ns
Error 2	16	0.47	1.25	1.08	0.01	0.02
Se	2	0.60ns	8.16**	3.38**	0.01ns	0.10**
Se × Y	2	0.03ns	0.01ns	0.01ns	0.01ns	0.01ns
Se × Fe	2	0.30ns	1.70*	1.43*	0.04*	0.04**
Se × S	4	0.76ns	7.70**	2.72**	0.01*	0.09**
Se × Fe × Y	2	0.01ns	0.01ns	0.01ns	0.01ns	0.01ns
Se × S × Y	4	0.06ns	0.01ns	0.04ns	0.01ns	0.01ns
Se × Fe × S	4	0.33ns	7.82**	9.13**	0.03**	0.17**
Se × Fe × S × Y	4	0.21ns	3.92**	4.58**	0.02**	0.08**
Error 3	48	1.34	0.49	0.31	0.01	0.01
CV (%)		1.27	2.31	4.45	6.32	6.91

SoV: Source of Variance; df: Degree of freedom; CV: Coefficient of variation; Y: Year; R: Replication; Fe: Iron; S: Sulfur; Se: Selenium; ns: non-significant; * Significant at the $p < 0.05$ level; ** Significant at the $p < 0.01$ level

Table 3. Mean square values for IV and saturated fatty acid compositions

SoV	df	IV	Palmitic Acid	Stearic Acid	Behenic Acid	Arachidic Acid
Y	1	9.07ns	0.04ns	0.07ns	0.73ns	0.04ns
R (Y)	4	2.64ns	0.07ns	0.01ns	0.01ns	0.02ns
Fe	1	4.15*	0.01ns	0.01ns	0.23**	0.18*
Fe × Y	1	0.01ns	0.04ns	0.01ns	0.09*	0.02ns
Error 1	4	0.29	0.01	0.01	0.01	0.01
S	2	3.95*	0.04ns	0.07**	1.35**	0.24**
S × Fe	2	0.03ns	0.01ns	0.01ns	0.02ns	0.28**
S × Y	2	1.88ns	0.24*	0.02ns	0.20**	0.21**
S × Fe × Y	2	0.02ns	0.02ns	0.01ns	0.14**	0.03*
Error 2	16	1.00	0.06	0.01	0.01	0.01
Se	2	1.14ns	0.32**	0.06**	0.63**	0.07**
Se × Y	2	0.01ns	0.02ns	0.01ns	0.04**	0.11**
Se × Fe	2	0.91ns	0.01**	0.01ns	0.06**	0.07**
Se × S	4	0.45ns	0.17**	0.06**	1.08**	0.13**
Se × Fe × Y	2	0.02ns	0.03ns	0.01ns	0.10**	0.01ns
Se × S × Y	4	0.11ns	0.02ns	0.01ns	0.01ns	0.04**
Se × Fe × S	4	9.17**	0.77**	0.14**	0.07**	0.30**
Se × Fe × S × Y	4	4.65**	0.39**	0.07**	0.05**	0.16**
Error 3	48	0.38	0.03	0.01	0.01	0.01
CV (%)		1.12	3.05	5.05	2.70	2.82

SoV: Source of Variance; df: Degree of freedom; CV: Coefficient of variation; Y: Year; R: Replication; Fe: Iron; S: Sulfur; Se: Selenium; ns: non-significant; * Significant at the $p < 0.05$ level; ** Significant at the $p < 0.01$ level

Unsaturated fatty acids

The peanut consists of oleic, linoleic, and linolenic acids, which are essential unsaturated fatty acids. They are the forerunners for plant hormones and take part in stress conditions (Chowdhury et al., 2015; Coniglio et al., 2023; Mingrou et al., 2022). Oleic acid, one of the important monounsaturated fatty acids, was found to be significant ($p < 0.05$) for Se, S x Se, and Fe x S x Se treatments but not for others, according to the results of

ANOVA (Table 3). The 3% Fe treatment had 56.88±0.21%, while the control group for Fe was 57.62±0.28% (Fig. 2b). The oleic acid varied between 56.64±0.27% and 57.69±0.38% for S treatments, and the maximum value was observed in 40S treatment. Besides, the oleic acid ranged from 56.87±0.26% to 57.79±0.38% for Se treatments, and 20Se came in first place with its highest value. The average value for oleic acid was 57.25±0.18%. For the triple interaction (Fe × S × Se), the combination of 0% Fe, 60 kg ha^{-1} S, and 40 ppm Se produced the highest oleic acid content (60.69%). It was reported that oleic acid was affected by genotypes and environmental conditions and varied between 43.89% and 55.46% (Gomaa & Nassaar, 2018). In addition, it was stated that the oleic acid content changes due to the effect of fertilizer type (Gironde et al., 2014; Hussein et al., 2019a). It was reported that S application caused a decrease in fatty acid content (Gironde et al., 2014), contrary to expectations, while a foliar application of 40 ppm Se caused an increase in some cultivars from 44.27% to 53.58% compared to the control (Hussein et al., 2019b). On the other hand, it was determined that fertilizer applications with different contents also affected the oleic acid content in various plants such as rapeseed and sesame (Mohammadi & Rokhzadi, 2012; Raza et al., 2018). Similar to the present study, it was reported that Se applications increased the oleic acid content in rapeseed plants (Liu et al., 2017).

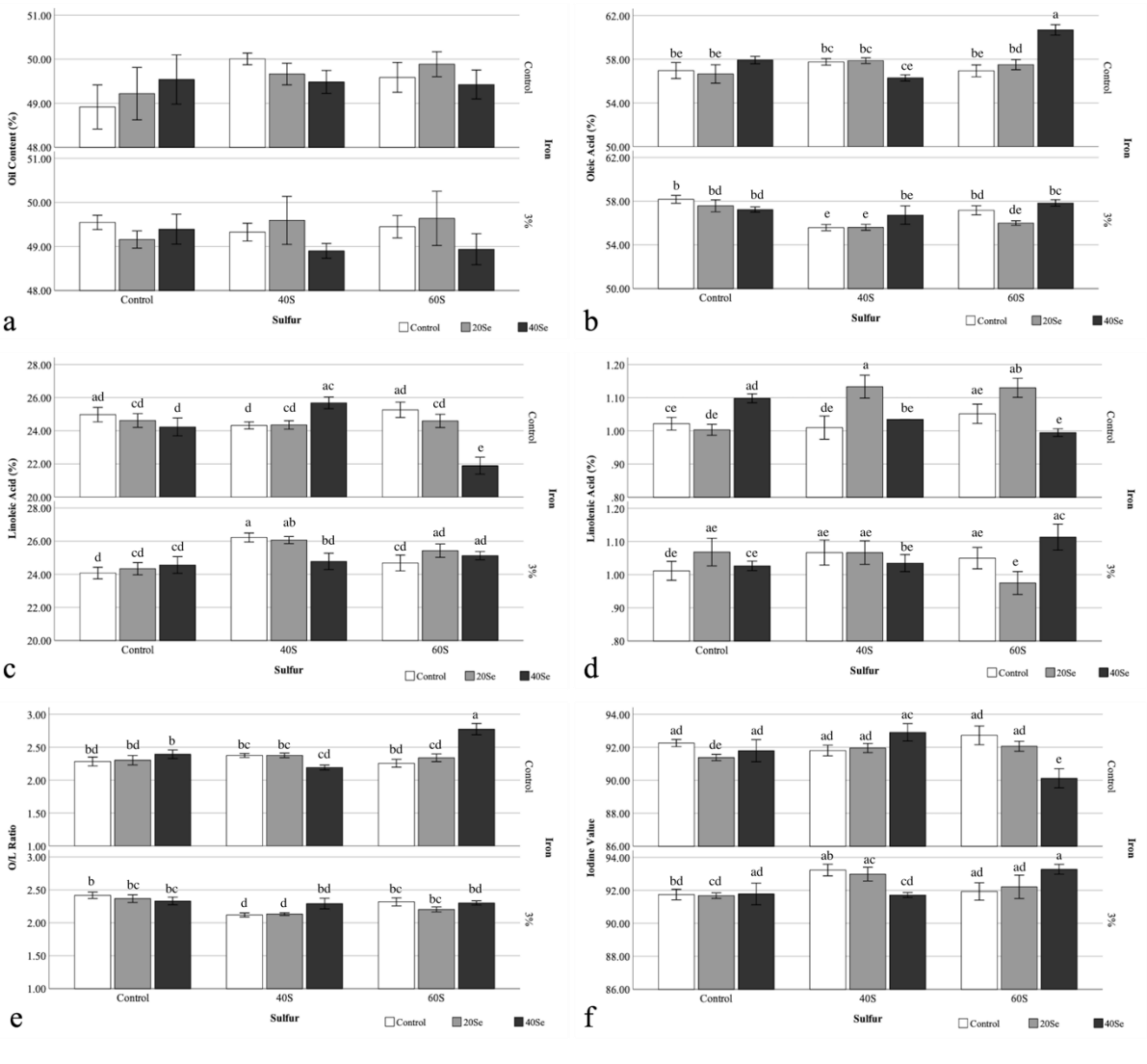

Figure 2. The 2-year average values of Fe x S x Se interaction for oil content, unsaturated fatty acids, and oil quality factors (a: oil content, b: oleic acid, c: linoleic acid, d: linolenic acid, e: O/L ratio, f: IV)

Linoleic acid, one of the important polyunsaturated fatty acids, was found to be significant ($p < 0.05$) for Fe, Se, S x Se, and Fe x S x Se treatments but not for others, according to the results (Gironde et al., 2014; Hussein et al., 2019b) of ANOVA. However, the other important polyunsaturated fatty acid, linolenic acid, was found to be significant ($p < 0.05$) for only Fe x S x Se treatment (Table 2). The 3% Fe and the control group were 25.03±0.17% and 24.44±0.23%, respectively (Fig. 2c). Linoleic acid contents ranged from 24.47±0.17% to 25.24±0.22% for S treatments, and 40S came in first place with its maximum value. On the contrary, linoleic acid contents varied between 24.38±0.33% and 24.92±0.21 for Se treatments, and the maximum value was observed in the control group, followed by 20Se treatment with 24.90±0.20% value. The average value for linoleic acid content was 24.74±0.15%. The highest linoleic acid content (26.22%) was observed in the 3% Fe × 40 kg ha^{-1} S × 0 ppm Se treatment combination. It was reported that there is a negative correlation between linoleic acid content and oleic acid content, which ranged from 24.11% to 37.17% depending on the variety and cultivation (Gomaa & Nassaar, 2018). Additionally, it was determined that S application caused a decrease in linoleic acid content, while Se application increased. With these applications, linoleic acid content varied between 26.11% and 36.68% (Gironde et al., 2014; Hussein et al., 2019b). While S-based fertilizer applications changed the linoleic acid content in various species, Se-containing fertilizers were found to have no statistical effect (Liu et al., 2017; Mohammadi & Rokhzadi, 2012). For linolenic acid contents, the 3% Fe treatment and the control group had similar values of 1.05±0.01% (Fig. 2d). Linolenic acid contents varied between 1.04±0.01% and 1.06±0.01% for S treatments, and the maximum value was observed in the 40S treatment. Additionally, linolenic acid contents ranged from 1.04±0.01% to 1.06±0.01% for the Se treatments, with 20Se achieving the highest value. The average value for linolenic acid content was 1.05±0.01%. The Fe × S × Se triple interaction was critical, with the 0% Fe × 40 kg ha^{-1} S × 20 ppm Se combination producing the maximum linolenic acid content (1.13%). It was stated that, in addition to oleic and linoleic acids, linolenic acid was one of the most important unsaturated fatty acids in peanuts, but it was found in minor amounts, varying between 1.36% and 3.16% (Gomaa & Nassaar, 2018). Similar to the current study, it was determined that Se applications had no significant effect on linolenic acid content, which varied between 1.12% and 1.76% (Hussein et al., 2019b; Liu et al., 2017). In addition, studies conducted with different species indicated that sulfur applications caused a decrease in linolenic acid content (Gironde et al., 2014).

Oil quality factors

A healthy life depends on the content of fatty acids in the consumption of peanuts. The rate of oleic to linoleic acid (O/L Ratio) and IV define the quality of its oil. Besides, the degree of unsaturated fatty acids and the stability of peanut oil are determined using IV. The peanut, which has high oleic acid content, has a longer shelf life than one with lower oleic acid content and has the best flavor quality or stability (Bilal et al., 2020; Gomaa & Nassaar, 2018; Zahran & Tawfeuk, 2019). O/L ratio was found to be significant ($p < 0.05$) for Fe, Se, S x Se, and Fe x S x Se treatments but not for others, according to the results of ANOVA. However, IV was found to be significant ($p < 0.05$) for only the Fe x S x Se treatment (Table 3). The 3% Fe and the control group were 2.28±0.02 and 2.37±0.03, respectively (Fig. 2e). O/L ratio ranged from 2.35±0.17 to 2.37±0.05 for S treatments, and 60S came in first place with its highest value. In other respects, the O/L ratio varied between 2.29±0.03 and 2.38±0.05 for Se treatments, and the highest value was observed in the 40Se treatment. The average value for the O/L ratio was 2.32±0.02. Similar results were obtained for IV; the 3% Fe treatment had 92.28±0.18, while the control group had 91.89±0.19 (Fig. 2f). IV varied between 91.77±0.16 and 92.43±0.19 for S treatments, and the lowest value was observed in the no S treatment. Besides, IV ranged from 92.05±0.18 to 92.28±0.19 for Se treatments, and the minimum value was observed in 40Se with an average of 92.09±0.13. Analysis of the Fe × S × Se triple interaction showed that the 0% Fe × 60 kg ha^{-1} S × 40 ppm Se treatment produced the most desirable oil quality profile, characterized by the highest O/L ratio (2.78) and the lowest IV (90.12). Although oleic acid and linoleic acid values were given in the literature, some did not mention the O/L ratio. If this ratio were calculated, it could be said that the O/L value generally varied between 1.2 and 2.3 (Gomaa & Nassaar, 2018). As expected, the higher the oleic acid content of the varieties, the higher the O/L ratio. According to a study conducted by Zahran & Tawfeuk (2019), the O/L ratio for peanut varied between 2.31 and 3.22. Hussein et al. (2019b) indicated that the O/L ratio was highest at 2.05 and lowest at 1.19 in Se applications. Gomaa & Nassaar (2018) reported that IV was affected by genotypes and environmental conditions, varying between 90.44 and 98.17. Similarly, Zahran & Tawfeuk (2019) also indicated that IV ranged from 86.71 to 90.90 in terms of genotypes and treatments. Similar results have been supported by studies conducted by Chowdhury et al. (2015) and Bilal et al. (2020).

Saturated fatty acids

Palmitic acid is one of the major fatty acids in peanuts, in addition to oleic and linoleic acids. Peanut oil also consists of saturated acids, such as stearic acid, behenic acid, and arachidic acid in minor percentages (Mingrou et al., 2022; Zahran & Tawfeuk, 2019). Palmitic acid was found to be significant ($p < 0.05$) for all independent variables except F, S, and F x Se treatments according to the results of ANOVA (Table 3). The 3% Fe treatment had 9.00±0.06%, while the control group for Fe was 8.98±0.04% (Fig. 3a). The palmitic acid varied between 8.97±0.05% and 9.02±0.07% for S treatments, and the maximum value was observed in the 40S treatment. Besides, the palmitic acid ranged from 8.91±0.05% to 9.09±0.04% for Se treatments, and the control group came in first place with its highest value, followed by 40Se treatment with the value of 8.96±0.07%. The average value for palmitic acid was 8.99±0.03%. Among the triple interaction treatments, the 3% Fe × 40 kg ha^{-1} S × 0 ppm Se combination resulted in the highest palmitic acid content at 9.35%. It ranked third in terms of quantity among the fatty acids found in peanut oil, varying between 12% and 15% (Gomaa & Nassaar, 2018; Zahran & Tawfeuk, 2019). It was reported that palmitic acid was not affected by S treatments (Gironde et al., 2014). However, foliar

Se-based spraying was found to be efficient and affected the palmitic acid content, and it ranged from 10.60% to 13.49% (Hussein et al., 2019b). Even if similar results for S treatments were also observed in different species (Mohammadi & Rokhzadi, 2012), some literature indicated that palmitic acid was found to be significant, in contrast to the present study (Raza et al., 2018; Shah et al., 2013).

Stearic acid content was found to be significant ($p < 0.05$) for all independent variables except Fe, Fe x S, and Fe x Se treatments according to the results of ANOVA (Table 3). The 3% Fe and the control group were 3.16±0.03% and 3.15±0.02%, respectively (Fig. 3b). Stearic acid contents ranged from 3.10±0.02% to 3.18±0.04% for S treatments, and 60S came in first place with its highest value, followed by the control group (3.18±0.02%). On the other hand, stearic acid contents varied between 3.10±0.02% and 3.18±0.03% for Se treatments, and the highest value was observed in the 40Se treatment. The average value for stearic acid content was 3.15±0.02%. The maximum stearic acid content (3.37%) was recorded for the 3% Fe × 60 kg ha^{-1} S × 0 ppm Se treatment combination in the Fe × S × Se triple interaction. Stearic acid was found in a lesser amount compared to palmitic acid and was affected by S- and Se-based fertilizer. It was reported that the value of stearic acid varied between 1.76% and 2.75%. (Gironde et al., 2014; Hussein et al., 2019b).

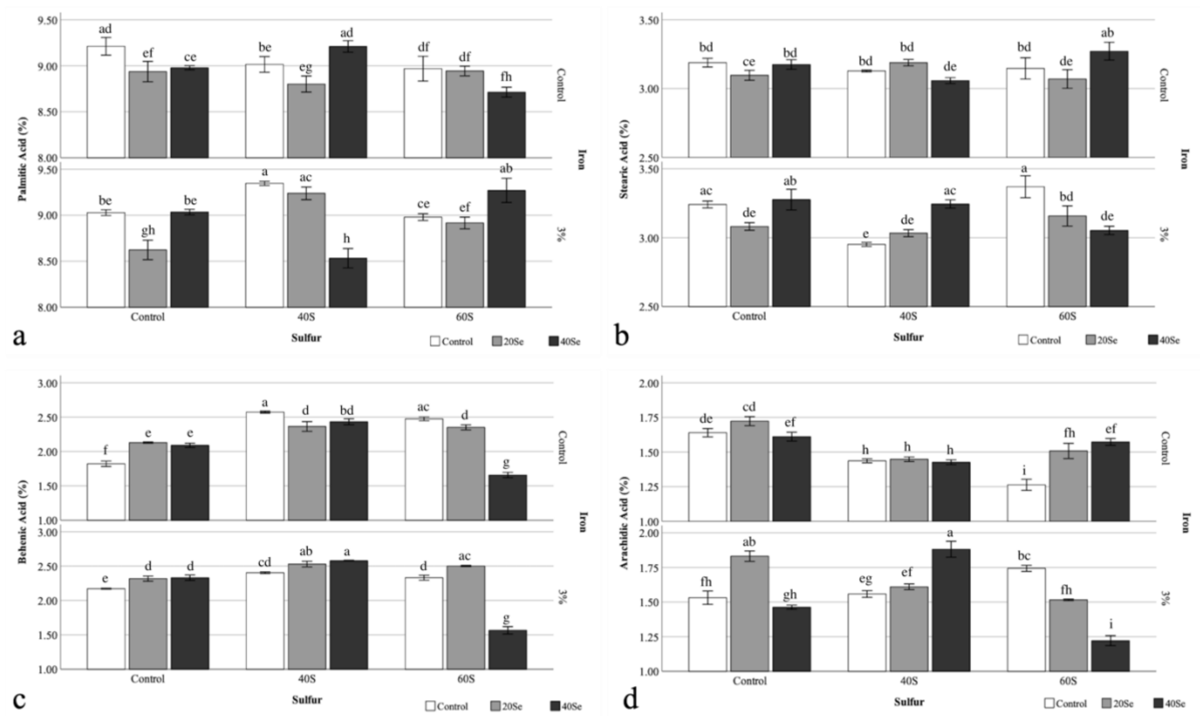

Figure 3. The 2-year average values of Fe x S x Se interaction for saturated fatty acids (a: palmitic acid, b: stearic acid, c: behenic acid, d: arachidic acid)

The behenic acid and arachidic acid contents were found to be significant ($p < 0.05$) for all independent variables and their interactions according to the results of ANOVA (Table 3). For behenic acid, the 3% Fe treatment had 2.30±0.06%, while the control group for Fe was 2.21±0.06% (Fig. 3c). The behenic acid contents varied between 2.14±0.04% and 2.48±0.02% for S treatments, and the maximum value was observed in the 40S treatment. Besides, behenic acid contents ranged from 2.11±0.09% to 2.37±0.03% for Se treatments, and 20Se came in first place with its highest value, followed by the control group with the value of 2.30±0.06%. The average value for behenic acid content was 2.26±0.04%. For arachidic acid, the 3% Fe and the control group were 1.60±0.04% and 1.51±0.03%, respectively (Fig. 3d). Arachidic acid contents ranged from 1.47±0.05% to 1.63±0.03% for S treatments, and the control group came in first place with its highest value, followed by 40S treatment (1.56±0.04%). On the other hand, arachidic acid contents varied between 1.53±0.03% and 1.61±0.03% for Se treatments, and the highest value was observed in the 20Se treatment. The average value for arachidic acid content was 1.56±0.02%. The 3% Fe × 40 kg ha^{-1} S × 40 ppm Se treatment combination produced the highest contents of both behenic acid (2.58%) and arachidic acid (1.88%) among all triple interactions. Peanut also consisted of stearic acid, as well as behenic and arachidic acid contents, in minor portions. Behenic and arachidic acids ranged from 0.97% to 2.06% and 1.75% to 2.75%, respectively, according to different Se doses (Hussein et al., 2019b). Similarly, these acids were affected by S treatments (Gironde et al., 2014).

4. CONCLUSION

Plant nutrients play a significant role in plant physiology, even when required in minor amounts. While most studies focus on single fertilizer effects, this study investigated the combined effects of soil-applied sulfur and foliar-applied iron and selenium on peanut oil content and quality. The results demonstrated that oil content was not significantly affected by the applications. However, oil quality was improved. The highest oleic acid content and O/L ratio, key indicators for oil stability, were achieved with soil applications of 40-60 kg S ha^{-1} and foliar applications of 20-40 ppm Se. The lowest iodine values (IV) were generally observed in the control groups for Fe and S and the 40 ppm Se treatment. A limitation of this study is the absence of plant tissue analysis to directly quantify the uptake of the applied nutrients, particularly for the foliar applications. Despite this, the consistent improvements in oil quality parameters lead to the conclusion that the combined use of soil-applied sulfur (40-60 kg ha^{-1}) and foliar-applied selenium (20-40 ppm) is an effective strategy to enhance peanut oil quality. Future studies incorporating nutrient uptake analysis will be valuable to confirm these findings and elucidate the underlying physiological mechanisms.

ACKNOWLEDGEMENT

The author is thankful to Dr. Mustafa Yilmaz for his assistance, to Dr. Merve Olukman Şahin for being in the author's life, and to Deniz Burak Şahin for sacrificing his playtime. The people who passed away in the earthquake that occurred on February 6, 2023, in Türkiye, will always be remembered. The author has no conflicts of interest to declare. The author agrees with the contents of the manuscript, and there is no financial interest to report.

REFERENCES

Ariraman, R., & Kalaichelvi, K. (2020). Effect of Sulphur Nutrition in Groundnut: A Review. *Agricultural Reviews*, *41*(2), 132–138. https://doi.org/10.18805/ag.r-1916

Babaeian, M., Tavassoli, A., Ghanbari, A., Esmaeilian, Y., & Fahimifard, M. (2011). Effects of foliar micronutrient application on osmotic adjustments, grain yield and yield components in sunflower (Alstar cultivar) under water stress at three stages. *African Journal of Agricultural Research, 6*(5), 1204–1208.

Bi, Y., Fan, C., Liang, W., Liao, Y., Han, D., Li, W., Chen, X., Liu, M., Liu, J., Di, S., Yang, G., Wang, Y., Liu, Y., Lai, Y., Lu, W., & Li, G. (2024). Combination Effects of Sulfur Fertilizer and Rhizobium Inoculant on Photosynthesis Dynamics and Yield Components of Soybean. *Agronomy*, *14*(4), 794. https://doi.org/10.3390/agronomy14040794

Bilal, M., Shabbir, M. A., Xiaobo, Z., Arslan, M., Usman, M., Azam, M., Aadil, R. M., & Ahmad, N. (2020). Characterization of peanut seed oil of selected varieties and its application in the cereal-based product. *Journal of Food Science and Technology*, *57*(11), 4044–4053. https://doi.org/10.1007/s13197-020-04437-y

Boydak, C., Kara, O., Arslan, R., Cil, A. N., Cil, A., Barut, H., & Irmak, S. (2019). Effects of Different Zinc and Iron Doses on Yield and Some Yield Components of NC-7 Peanut (*Arachis hypogaea* L.). *Journal of the Faculty of Agriculture*, *14*(2), 134–142.

Brooks, K., Mourtzinis, S., Conley, S. P., Reiter, M. S., Gaska, J., Holshouser, D. L., Irby, T., Kleinjan, J., Knott, C., Lee, C., Lindsey, L., Naeve, S., Ross, J., Singh, M. P., Vann, R., & Matcham, E. (2023). Soybean yield response to sulfur and nitrogen additions across diverse U.S. environments. *Agronomy Journal*, *115*(1), 370–383. https://doi.org/10.1002/agj2.21216

Cannon, K., McClure, M. A., Yin, X., & Sams, C. (2021). Corn and soybean response to sulfur fertilizer in West Tennessee. *Crop, Forage & Turfgrass Management*, *7*(1), e20092. https://doi.org/10.1002/cft2.20092

Chhonkar, A. K., & Chandel, A. S. (1991). Effect of iron and molybdenum on nitrogenase activity and nitrogen fixation in soybean (*Glycine max* L.) grown in alluvial soils of North India. *Indian Journal of Agronomy, 36*(Suppl.), 124–128.

Chowdhury, M. F. N., Hossain, D., Hosen, M., & Rahman, S. (2015). Comparative study on chemical composition of five varieties of groundnut (*Arachis hypogaea*). *World Journal of Agricultural Sciences*, *11*(5), 247–254. https://doi.org/10.5829/idosi.wjas.2015.11.5.1864

Coniglio, S., Shumskaya, M., & Vassiliou, E. (2023). Unsaturated Fatty Acids and Their Immunomodulatory Properties. *Biology*, *12*(2), 279. https://doi.org/10.3390/biology12020279

Deliboran, A., Isik, Y., Aslan, H., Nacar, A. S., Tekgul, T. Y., Kara, H., Harmankaya, M., & Gezgin, S. (2018). The effect of selenium application on yield parameters, selenium, protein and oil contents of grain maize. *Journal of Soil Science and Plant Nutrition*, *6*(1), 1–11.

Dogan, K., Gok, M., Coskan, A., & Guvercin, E. (2007). Effects of bacteria inoculation and iron application on nodulation and N-fixation in groundnut plants. *Journal of Agriculture Faculty*, *2*(1), 35–46.

Erhunmwunse, A. S., & Farmaha, B. S. (2023). Soybean response to potassium, magnesium, and sulfur fertilization on Southeastern Coastal Plain soils. *Agrosystems, Geosciences & Environment*, *6*(1), e20333. https://doi.org/10.1002/agg2.20333

Food and Agriculture Organization of the United Nations [FAO]. (2025). *FAOSTAT*. https://www.fao.org/faostat/, (Accessed August 20, 2025)

Ghasemian, V., Ghalavand, A., Soroosh Zadeh, A., & Pirzad, A. (2010). The effect of iron, zinc, and manganese on quality and quantity of soybean seed. *Journal of Phytological Research, 2*(11), 73–79.

Gironde, A., Dubousset, L., Trouverie, J., Etienne, P., & Avice, J.-C. (2014). The impact of sulfate restriction on seed yield and quality of winter oilseed rape depends on the ability to remobilize sulfate from vegetative tissues to reproductive organs. *Frontiers in Plant Science*, *5*. https://doi.org/10.3389/fpls.2014.00695

Gomaa, R. A., & Nassaar, S. M. A. (2018). Evaluation of some new peanut oil varietiles. *Minia Journal of Agricultural Research and Development*, *38*(4), 671–682.

Guvercin, E., & Gok, M. (2022). Effect of bacteria inoculation and iron application rates on nodulation and yield of different peanut varieties. *Journal of the Faculty of Agriculture*, *17*(1), 34–39. https://doi.org/10.54975/isubuzfd.1089567

Haddadi, M., Amiri, E., Ashouri, M., Sadeghi, S. M., & Mohammadiyan Roshan, N. (2024). Effect of water stress on yield and yield components of peanut cultivars. *Turkish Journal Of Field Crops*, *29*(2), 177–189. https://doi.org/10.17557/tjfc.1386899

Hussein, H.-A. A., Darwesh, O. M., & Mekki, B. B. (2019a). Environmentally friendly nano-selenium to improve antioxidant system and growth of groundnut cultivars under sandy soil conditions. *Biocatalysis and Agricultural Biotechnology*, *18*, 101080. https://doi.org/10.1016/j.bcab.2019.101080

Hussein, H.-A. A., Darwesh, O. M., Mekki, B. B., & El-Hallouty, S. M. (2019b). Evaluation of cytotoxicity, biochemical profile and yield components of groundnut plants treated with nano-selenium. *Biotechnology Reports*, *24*, e00377. https://doi.org/10.1016/j.btre.2019.e00377

Irmak, S. (2017). Effects of selenium application on plant growth and some quality parameters in peanut (*Arachis hypogaea*). *Pakistan Journal of Biological Sciences*, *20*(2), 92–99. https://doi.org/10.3923/pjbs.2017.92.99

Kinaci, E., & Gulmezoglu, N. (2007). Grain yield and yield components of triticale upon application of different foliar fertilizers. *Interciencia, 32*(9), 624–628.

Kumar, D., & Sidhu, S. S. (2013). Response of soybean to soil applied sulfur and boron in a calcareous soil. *Journal of Plant Nutrition*, *36*(11), 1795–1807. https://doi.org/10.1080/01904167.2013.805223

Kur, A. B., Beycioglu, T., & Killi, F. (2019). Peanut (*Arachis hypogaea* L.) response to iron foliar application (EDDHA-Fe) at different growth stages and doses. *International Journal of Anatolia Agricultural Engineering*, *1*(5), 13–16.

Liu, X., Yang, Y., Deng, X., Li, M., Zhang, W., & Zhao, Z. (2017). Effects of sulfur and sulfate on selenium uptake and quality of seeds in rapeseed (*Brassica napus* L.) treated with selenite and selenate. *Environmental and Experimental Botany*, *135*, 13–20. https://doi.org/10.1016/j.envexpbot.2016.12.005

Mingrou, L., Guo, S., Ho, C., & Bai, N. (2022). Review on chemical compositions and biological activities of peanut (*Arachis hypogeae* L.). *Journal of Food Biochemistry*, *46*(7), 1–16. https://doi.org/10.1111/jfbc.14119

Mohammadi, K., & Rokhzadi, A. (2012). An integrated fertilization system of canola (*Brassica napus* L.) production under different crop rotations. *Industrial Crops and Products*, *37*(1), 264–269. https://doi.org/10.1016/j.indcrop.2011.12.023

Moreira, A., & Moraes, L. A. C. (2016). Sulfur use efficiency in soybean cultivars adapted to tropical and subtropical conditions. *Communications in Soil Science and Plant Analysis*, *47*(19), 2208–2217. https://doi.org/10.1080/00103624.2016.1228949

Nasri, M., Khalatbari, M., & Aliabadi Farahani, H. (2011). Zn-foliar application influence on quality and quantity features in Phaseolus vulgaris under different levels of N and K fertilizers. *Advances in Environmental Biology, 5*(5), 839–846.

Petkovic, K., Manojlovic, M., Lombnæs, P., & Cabilovic, R. (2019). Foliar application of selenium, zinc and copper in alfalfa (*Medicago sativa* L.) biofortification. *Turkish Journal of Field Crops*, *24* (1), 81–90. https://doi.org/10.17557/tjfc.569363

Pezzarossa, B., Remorini, D., Gentile, M. L., & Massai, R. (2012). Effects of foliar and fruit addition of sodium selenate on selenium accumulation and fruit quality. *Journal of the Science of Food and Agriculture*, *92*(4), 781–786. https://doi.org/10.1002/jsfa.4644

Raza, M. A., Feng, L. Y., Manaf, A., Wasaya, A., Ansar, M., Hussain, A., Khalid, M. H. B., Iqbal, N., Xi, Z. J., Chen, Y. K., Chen, J. X., Yang, F., & Yang, W. (2018). Sulphur application increases seed yield and oil content in sesame seeds under rainfed conditions. *Field Crops Research*, *218*, 51–58. https://doi.org/10.1016/j.fcr.2017.12.024

Sadat Darakeh, S. A. S., Weisany, W., Diyanat, M., & Ebrahimi, R. (2021). Bio-organic fertilizers induce biochemical changes and affect seed oil fatty acids composition in black cumin (*Nigella sativa* Linn). *Industrial Crops and Products*, *164*, 113383. https://doi.org/10.1016/j.indcrop.2021.113383

Sahin, C. B., & Isler, N. (2021). Foliar applied zinc and iron effects on yield and yield components of soybean: determination by PCA analysis. *Communications in Soil Science and Plant Analysis*, *52*(3), 212–221. https://doi.org/10.1080/00103624.2020.1854297

Sahin, C. B., Yilmaz, M., & Isler, N. (2022). Determination of oil quality and fatty acid compositions of some peanut (*Arachis hypogaea* L.) genotypes grown in Mediterranean region. *Turkish Journal Of Field Crops*, *27*(1), 142–148. https://doi.org/10.17557/tjfc.1095649

Shah, M. A., Manaf, A., Hussain, M., Farooq, S., & Zafar-ul-Hye, M. (2013). Sulphur fertilization improves the sesame productivity and economic returns under rainfed conditions. *International Journal of Agriculture and Biology*, *15*(6), 1301-1306.

Shao, S., Ma, B., Ai, L., Tian, X., & Zhang, L. (2022). Foliar spraying of selenium combined with biochar alleviates cadmium toxicity in peanuts and enriches selenium in peanut grains. *International Journal of Environmental Research and Public Health*, *19*(6), 3542. https://doi.org/10.3390/ijerph19063542

Saleem, S., Mushtaq, N. U., Rasool, A., Shah, W. H., Tahir, I., & Rehman, R. U. (2023). Plant nutrition and soil fertility: Physiological and molecular avenues for crop improvement. In T. Aftab & K. R. Hakeem (Eds.), *Sustainable plant nutrition* (pp. 23–49). Academic Press. https://doi.org/10.1016/B978-0-443-18675-2.00009-2

Steel, R. G. D., & Torrie, J. H. (1980). *Principles and procedures of statistics: A biometrical approach* (2nd ed.). McGraw-Hill Book Company.

Sytar, O., Kosyan, A., Taran, N., & Okanenko, A. (2012). Impact of lead and sulfur deprivation on soybean plants. In L. De Kok et al. (Eds.), *Sulfur metabolism in plants: Proceedings of the International Plant Sulfur Workshop* (pp. 271–277). Springer. https://doi.org/10.1007/978-94-007-4450-9_33

Topuz, A., & Topal, N. (2021). Selenium metabolism in plants and using in agriculture. *Uşak University Journal of Science and Natural Sciences*, *5*(1), 87–99. https://doi.org/10.47137/usufedbid.854811

Turan, M., & Horuz, A. (2012). Major principles of plant nutrition. In M. R. Karaman (Ed.), *The plant nutrition* (pp. 123-345). Dumat Ofset.

Turkish Statistical Institute [TUIK]. (2025). *Agricultural production statistics*. https://data.tuik.gov.tr/, (Accessed August 20, 2025)

Turkish State Meteorological Service [TSMS]. (2024). *Meteorological database (MEVBIS)*. https://mevbis.mgm.gov.tr/, (Accessed August 20, 2025)

Vinothini, R., Kaleeswari, R. K., Selvi, D., Uma, D., & Devi, E. K. (2022). Screening of groundnut genotypes for sulphur utilization potential. *International Journal of Plant & Soil Science*, 10–16. https://doi.org/10.9734/ijpss/2022/v34i330841

Yilmaz, M., Sahin, C. B., Yildiz, D., Demir, G., Yildiz, R., & Isler, N. (2022). General situation of peanut (*Arachis hypogaea*) production in the world and in Turkey, major problems and solution suggestions. *Mus Alparslan University Journal of Agriculture and Nature*, *2*(1), 8–17.

Zahran, H. A., & Tawfeuk, H. Z. (2019). Physicochemical properties of new peanut (*Arachis hypogaea* L.) varieties. *OCL*, *26*, 19. https://doi.org/10.1051/ocl/2019018

Zayed, B. A., Salem, A. K. M., & Sharkawy, H. M. E. (2011). Effect of different micronutrient treatments on rice (*Oriza sativa* L.) growth and yield under saline soil conditions. *World Journal of Agricultural Sciences*, *7*(2), 179–184.

Zhou, Y., Xiao, C., Yang, S., Yin, H., Yang, Z., & Chi, R. (2021). Life cycle assessment and life cycle cost analysis of compound microbial fertilizer production in China. *Sustainable Production and Consumption*, *28*, 1622–1634. https://doi.org/10.1016/j.spc.2021.09.003