Effect of Sulfur Levels and genotype on Leaf Area, NPK Content, Seed Yield and Oil Percentage of Sesame (*Sesamum indicum* L.)

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Abstract

The field experiment was conducted north of Kirkuk city at the Kirkuk Agriculture Directorate's research center in the Al-Hisar area of Shwan sub-district, approximately 30 km from the city center, at latitude 35.633435° North and longitude 44.37987° East. The experiment aimed to study the effect of sulfur levels and varietal performance on the growth, yield, and oil content of sesame. The experiment was conducted using a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The main plots included the three applied sulfur levels (0, 750 kg ha^{-1}, and 1500 kg ha^{-1}). The subplots included the ten genotypes (Rafidain, Baytim, Wadaa, GOLMMUROS, NAGHAL157, Mahli, Had, Malaysian Black, Giza, and Sumer). Each replication consisted of 30 experimental units, for a total of 90 experimental units. An experimental unit was used, and each replicate included three main plots (levels of added sulfur). Each main plot contained ten subplots, which were sesame genotypes randomly distributed within the replicate. The results were as follows: The treatment with added sulfur at a concentpercentagen of 750 kg ha^{-1} was excelled, recording the highest average for plant height (178.9 cm), leaf chlorophyll content (56.6 Spad), and seed yield (2136.9 kg.ha^{-1}). In contrast, the treatment with sulfur at a level of 1500 kg ha^{-1} achieved the highest average number of capsules (182.4 capsules per plant) and oil content (50.6%). Regarding genotypes, Wadaa genotype was excelled in leaf chlorophyll content (56.7 Spad), number of seeds per capsule (86.1 seeds per capsule), and seed yield (2687.7). The Giza genotype recorded the highest average for 1000-seed weight (3.1). Regarding the interaction between genetic makeup and sulfur levels, the results showed a significant increase in the interaction coefficients for most of the studied traits.

Keywords: genetic makeup, sesame, sulfur

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Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest cash and oilseed crops in the world, cultivated for its seeds, which are among the richest crop seeds in fats. Its seeds contain oil, with a percentage ranging between 50-65%. Its oil consists mainly of unsaturated triglycerides of fatty acids such as oleic and linoleic acids, among others. Sesame belongs to the Pedaliaceae family and has the ability to adapt to dry and semi-dry conditions [10]. Sulfur is one of the essential nutrients for plant growth and is usually considered the fourth most important nutrient after nitrogen, phosphorus, and potassium. It is involved in the structure of three essential amino acids for plants, such as cysteine, cysteine, and methionine, which are among the most important sulfur-containing amino acids in plants. These exist as free amino acids and act as building blocks for protein synthesis. They also help activate some enzymes and are involved in photosynthesis [6]. Some studies have shown that adding sulfur improves the growth of oil crops, leading to improved oil quality and protein content in the seeds. Especially in soils deficient in sulfur[3,11].Sulfur is a powerful fungicide against fungal diseases and is effective in controlling soil fungi such as Fusarium, Verticillium, and Rhizoctonia. Its application also acts as a powerful soil disinfectant.

Materials and Methods

Genotypes:

Ten sesame genotypes from different sources were used, in addition to the local variety commonly cultivated in Iraq, as shown in Table (1).

The compositions are as follows: Rafidain, Baytim, Wadaa, GOLMMUROS, NAGHAL157, Local, Had, Malaysian Black, Giza, Sumer

Experiment Implementation:

The field experiment was conducted north of Kirkuk city at the Kirkuk Agriculture Directorate's research center in the Al-Hisar area of Shwan sub-district, approximately 30 km from the city center, at latitude 35.633435° North and longitude 44.37987° East. The land was plowed twice perpendicularly using a moldboard plow, then the soil was smoothed using available smoothing equipment. The field was divided according to the design used before planting, and NPK fertilizer (1 kg/ha) was added in a single application at planting time.The experiment was conducted according to a randomized complete block design (RCBD) with a split-plot arrangement and three replicates. The main plots contained the three added sulfur levels (0, 750 kg ha^{-1}, and 1500 kg ha^{-1}), and the subplots contained the ten genotypes. Each replicate included 30 experimental units, for a total of 90 experimental units. Each replicate contained three main plots (added sulfur levels), and each main plot contained ten subplots (sesame genotypes) randomly distributed within the replicate. The area of the main plot was

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40 m², and each experimental unit consisted of five rows (2 x 2 = 4 m²) with a spacing of 40 cm between rows and 20 cm between plants. Planting took place on June 1, 2025. Thinning and patching opepercentagens were carried out, measurements were taken, and the genotypes of each structure were harvested according to their maturity. Five genotypes were harvested per experimental unit, and data were collected. After randomly selecting the soil composition and excluding terminal plants, all measurements were taken. Soil samples were collected from the field by taking 200 grams from each corner and from the center of the field at a depth of 30 cm, for a total weight of 1000 grams. A sample of irrigation water was also taken. The physical and chemical properties were measured at the Kirkuk Agriculture Directorate laboratory, as shown in Table 2.

Table 1: Analysis of the Physical and Chemical Properties of Soil and Water

tests	units	Results:	
		Water	Soil,
EC	$Ds.cm^{-1}$	0.428	0.190
PH		7.48	7.90
TDS	$mg.kg^{-1}$	274.032	121.326
Available nitrogen	$mg.kg^{-1}$		22.220
Available phosphorus	$mg.kg^{-1}$		9.813
Available potassium	mg.kg-1		213.959
Sulfate	$mg.kg^{-1}$		30.021
Organic matter	%		0.690
texture			Silt Loam
Clay	%		4
Silt	%		58
Sand	%		38

Studied Sesame traits:

Leaf Area:

The leaf area was calculated as an average for five randomly selected plants using the following equation:

$$LA(cm^2) = 0.3552 \times C(cm)$$

LA = Leaf Area (cm^2)

C = Estimated Maximum Leaf Length (cm)

Estimation of Nutrient (NPK) Content in the Vegetative Part during Capsule Formation:

The nitrogen, phosphorus, and potassium content in the vegetative part

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during capsule formation was estimated using standard plant analysis methods.

Seed Yield:

The seed yield per unit area was estimated by multiplying the average yield of an individual plant by the plant density for each experimental unit.

Oil Percentage (%):

The oil percentage in the seeds was measured using a sexlot. Five grams of ground, dry seeds were placed in the extraction apparatus using solvents. After the solvent evaporated, the samples were weighed, and the oil percentage was calculated using the following equation:

Oil Percentage (%) = Weight of Sample Before Extraction (g) / Weight of Sample After Extraction (g) × 100

Results Discussion

Leaf Area Traits (cm²)

The results in the table showed clear and significant differences between sulfur levels in leaf area traits, where the 1500 kg ha^{-1} level was significantly excelled, recording the highest average of 2028.6 cm², compared to the 750 kg ha^{-1} level and the no-sulfur treatment, which recorded the lowest average of 1532.2 cm². This excelled is attributed to the important physiological role of sulfur in increasing chlorophyll formation and improving the efficiency of photosynthesis, which leads to increased leaf growth and an expansion of leaf area [14].

Regarding the effect of genotypes, the results showed no significant differences between the genotypes in leaf area, despite numerical differences. The Wadaa genotype recorded the highest average leaf area at 1936.9 cm², while the Rafidain genotype recorded the lowest average at 1563.9 cm². The lack of significant differences may be due to the genetic similarity between the studied genotypes or to the dominance of sulfur levels over the effect of individual genotypes in this trait [12].The interaction between sulfur levels and genotype also showed significant differences. The interaction between Bytem and the 1500 kg ha^{-1} level recorded the highest value at 2628.4 cm², while the interaction between Rafidain and the control treatment recorded the lowest value at 960.0 cm². This variation indicates the different efficiency of plant structures in responding to sulfur levels and their ability to utilize it to improve vegetative growth and increase leaf area. Numerous studies have confirmed that a genotype's response to sulfur fertilization varies according to its genetic traitss and its efficiency in absorbing and utilizing nutrients[1,9]. The results showed significant differences in leaf area between sulfur levels, with the 1500 kg ha^{-1} level significantly exceeding the sulfur level, while the no-apply treatment recorded the lowest values. No significant differences were found between plant structures in the average annual result.

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However, the interaction between sulfur levels and plant structures had a significant effect, indicating the different responses of plant structures to sulfur levels.

Table (2) shows the arithmetic means of the effect of sulfur levels, plant structures, and their interaction on leaf area (cm^2).

genotype	Sulfur levels			average genotype
	Zero	750kg·ha⁻¹	1500kg·ha⁻¹	
Al-Rafidain	960.0[e]	1461.4[b-e]	2270.5[ab]	1563.9[a]
Baytim	916.3[e]	2032.8[abc]	2628.4[a]	1859.2[a]
Local	1167.1[de]	1757.5[b-e]	2061.1[abc]	1661.9[a]
Had	1712.2[b-e]	1847.7[a-d]	2224.4[ab]	1928.1[a]
Giza	1479.9[b-e]	1641.5[b-e]	1969.7[a-d]	1697.0[a]
COLMMUROS	1611.7[b-e]	1498.8[b-e]	1993.5[a-d]	1701.3[a]
Malaysian Black	1744.5[b-e]	1889.3[a-d]	1849.8[a-d]	1827.9[a]
NAGHAL 157	1744.6[b-e]	1407.0[b-e]	1710.6[b-e]	1620.8[a]
Summer	1739.2[b-e]	1286.1[cde]	1946.4[a-d]	1657.2[a]
Wadaa	2246.6[ab]	1932.7[a-d]	1631.5[b-e]	1936.9[a]
Average Sulfur Levels	1532.2[c]	167.5[b]	2028.6[a]	

*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.

The traits of estimating the percentage of elements (NPK) in the vegetative part during the capsule formation stage:

The results in the table showed significant differences between sulfur levels in the nitrogen percentage traits of the seeds. The 1500 kg ha^{-1} level recorded the highest average at 3.9%, while the 750 kg ha^{-1} level recorded an average of 3.5%. The treatment without adding sulfur recorded the lowest average at 3.1%. This increase in nitrogen percentage is attributed to the role of sulfur in improving the absorption of nutrients, especially nitrogen, as well as its involvement in the formation of amino acids and proteins, which positively impacts the plant's nitrogen content[9,13] .Regarding the genotypes, the results showed significant differences between them. The Wadaa genotype significantly excelled others, recording the highest average nitrogen percentage at 3.8%, while the Rafdain genotype recorded the lowest average at 3.3%.

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This variation may be attributed to genetic differences in the efficiency of the genotypes in absorbing and assimilating nutrients within the plant [12]..The results also showed a significant interaction between sulfur levels and genotype. The Wadaa genotype, when fertilized at 1500 kg ha^{-1}, recorded the highest nitrogen percentage at 4.3%, while the Rafdain genotype, when fertilized without sulfur, recorded the lowest at approximately 2.9%. This indicates a difference in the genotype's response to sulfur levels and its ability to utilize sulfur fertilization to improve its nitrogen content [5].

Table (3) Arithmetic means of the effect of sulfur levels, structures and the interaction between them on the nitrogen percentage traits

genotype	Sulfur levels			average genotype
	Zero	750kg·ha^{-1}	1500 kg·ha^{-1}	
Al-Rafidain	209^{no}	3.4^{ijk}	3.6^{e-h}	3.3^{e}
Baytim	2.9^{o}	3.4^{ijk}	3.8^{cde}	3.3^{ed}
Local	3.1^{lm}	3.5^{ghi}	3.9^{bcd}	3.5^{bc}
Had	3.0^{mno}	3.3^{kl}	3.7^{def}	3.3^{e}
Giza	3.11^{mn}	3.5^{hij}	3.9^{bcd}	3.5^{bc}
COLMMUROS	3.1^{lm}	3.6^{f-i}	4.0^{b}	3.6^{b}
Malaysian Black	3.1^{lm}	3.5^{f-i}	3.9^{bcd}	3.5^{bc}
NAGHAL 157	3.2^{lm}	3.6^{f-i}	4.0^{bc}	3.6^{bc}
Summer	3.1^{mn}	3.5^{h-k}	3.8^{cde}	3.4^{cd}
Wadaa	3.3^{jkl}	3.7^{d-g}	4.3^{a}	3.8^{a}
Average Sulfur Levels	3.1^{c}	3.5^{b}	3.9^{a}	

*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.

The table results showed significant differences in sulfur levels and their impact on phosphorus content in the seeds. The 1500 kg ha^{-1} level recorded the highest average at 0.4%, while the 750 kg ha^{-1} level recorded an average of 0.3%. The control treatment recorded the lowest average at 0.2%. This increase is attributed to sulfur's role in enhancing nutrient absorption, including phosphorus. Sulfur contributes to increased efficiency in mineral absorption and improved metabolic activity within the plant, which positively impacts the plant's phosphorus content[5,7] .Regarding the genotypes, the results showed significant differences between them. The NAGHAL 157 genotype recorded the highest average phosphorus content at 0.4%, while some genotypes, such as

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Rafidain, Baytim, Had, and Sumer, recorded the lowest average at approximately 0.3%. This variation may be attributed to genetic differences between the genotypes in their ability to absorb nutrients and their efficiency in assimilate phosphorus within the plant [12].The results also showed a significant interaction between sulfur levels and genotype. The interaction between NAGHAL 157 and the 1500 kg ha^{-1} level recorded the highest phosphorus percentage value at 0.5%, while the interaction between Rafidain and Baytim and the no-sulfur level recorded the lowest value at 0.2%. This indicates a difference in the genotype's response to sulfur levels and its ability to utilize sulfur fertilization to improve nutrient uptake, including phosphorus [9].

Table (4) shows the arithmetic means of the effect of sulfur levels, compositions, and their interaction on the phosphorus percentage traits.

genotype	**Sulfur levels**			**average genotype**
	Zero	**750kg·ha^{-1}**	**1500 kg·ha^{-1}**	
Al-Rafidain	0.2^{g}	0.3^{d-g}	0.3^{b-e}	0.3^{c}
Baytim	0.2^{g}	0.3^{d-g}	0.3^{b-f}	0.3^{c}
Local	0.2^{efg}	0.3^{c-g}	0.4^{bcd}	0.3^{bc}
Had	0.2^{fg}	0.3^{d-g}	0.3^{b-f}	0.3^{c}
Giza	0.2^{g}	0.3^{c-g}	0.4^{b-e}	0.3^{bc}
COLMMUROS	0.3^{d-g}	0.3^{c-g}	0.4^{bc}	0.3^{abc}
Malaysian Black	0.2^{g}	0.3^{d-g}	0.4^{bcd}	0.3^{bc}
NAGHAL 157	0.2^{g}	0.3^{c-g}	0.5^{a}	0.4^{ab}
Summer	0.2^{fg}	0.3^{d-g}	0.3^{b-e}	0.3^{c}
Wadaa	0.3^{d-g}	0.4^{b-e}	0.5^{ab}	0.3^{a}
Average Sulfur Levels	0.2^{c}	0.3^{b}	0.4^{a}	

*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.

The table showed significant differences in sulfur levels and potassium content in the seeds. The 1500 kg ha^{-1} level recorded the highest average at 2.7%, while the 750 kg ha^{-1} level recorded an average of 2.5%. The control treatment recorded the lowest average at 2.3%. This is attributed to the role of sulfur in improving nutrient absorption efficiency and activating physiological processes within the plant, which contributes to increased absorption of minerals, including potassium, and consequently higher potassium concentpercentagen in plant tissues[5,7] .Regarding the genotypes,

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the results showed significant differences between them. The Wadaa genotype significantly excelled others, recording the highest average potassium content at 2.8%, while the Rafdain genotype recorded the lowest average at 2.3%. This variation is attributed to genetic differences between plant structures in their ability to absorb nutrients and their efficiency in transporting and accumulating potassium within the plant [12].The results also showed a significant interaction between sulfur levels and genotype. The interaction with 1500 kg ha^{-1} sulfur resulted in the highest potassium percentage value of 3.1%, while the interaction with no sulfur application resulted in the lowest value of 2.1%. This indicates a difference in the genotype's response to sulfur levels and its ability to utilize sulfur fertilization to improve nutrient uptake, including potassium [9].

Table (5) shows the arithmetic means of the effect of sulfur levels, plant structures, and their interaction on potassium percentage.

genotype	**Sulfur levels**			**average genotype**
	Zero	**750 kg·ha⁻¹**	**1500 kg·ha⁻¹**	
Al-Rafidain	2.1^{q}	2.4^{lmn}	2.5^{f-i}	2.3^{g}
Baytim	2.2^{p}	2.4^{k-n}	2.5^{g-j}	2.4^{f}
Local	2.4^{klm}	2.5^{h-k}	2.6^{def}	2.5^{c}
Had	2.2^{p}	2.4^{j-m}	2.6^{e-h}	2.4^{ef}
Giza	2.3^{nop}	2.5^{h-k}	2.6^{def}	2.5^{cd}
COLMMUROS	2.3^{nop}	2.6^{d-g}	2.9^{b}	2.6^{b}
Malaysian Black	2.2^{p}	2.5^{h-l}	2.6^{d-g}	2.4^{def}
NAGHAL 157	2.3^{op}	2.5i^{-m}	2.7^{de}	2.5^{cd}
Summer	2.2^{p}	2.4^{j-m}	2.7^{cd}	2.5^{cde}
Wadaa	2.4^{mno}	2.8^{bc}	3.1^{a}	2.8^{a}
Average Sulfur Levels	2.3^{c}	2.5^{b}	2.7^{a}	

*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.

Seed Yield Traits: $kg.ha^{-1}$

The results of the seed yield table indicate clear and significant differences between the studied formulations and sulfur levels, as well as a significant interaction between the two factors. This suggests a variation in the genetic response of the varieties to sulfur fertilization. Some formulations showed a marked improvement in seed yield when sulfur was added compared to the control group. This is attributed to the vital role of sulfur in enhancing

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photosynthetic efficiency and activating metabolic processes related to protein and oil formation, which positively impacts seed formation and plumpness.

Furthermore, sulfur addition contributed to improved absorption of macronutrients, particularly nitrogen and phosphorus, by enhancing the soil's chemical properties and reducing its pH. This leads to increased nutrient availability for the plant, resulting in improved vegetative and reproductive growth and increased seed yield. Several researchers have indicated that sulfur is a limiting element for oilseed production due to its essential role in the formation of sulfur-containing amino acids and enzymes responsible for dry matter accumulation in seeds[12,14] .

The results show that moderate sulfur levels resulted in higher average seed yields in some varieties compared to high levels. This suggests that the response to sulfur depends not only on quantity but also on the efficiency of the genetic makeup in utilizing the element, as excessive sulfur may not necessarily lead to a further increase in yield. These findings are consistent with those of [2,6] who confirmed that optimal seed yield is achieved at moderate sulfur levels appropriate to the genetic makeup of the variety and soil conditions. The excelled seed yield of certain formulations reflects their higher physiological efficiency in converting photosynthetic products into seeds, in addition to their positive response to sulfur fertilization, making them more suitable for cultivation under conditions similar to those of the experiment. These results indicate the importance of selecting the appropriate formulation with the optimal sulfur level to achieve the highest possible seed yield, a point confirmed by several recent studies on oilseed crops [4,8] .

Table 6: Arithmetic Means of the Effect of Sulfur Levels, Formations, and Their Interaction on Seed Yield

genotype	**Sulfur levels**			**average genotype**
	Zero	**750 kg·ha^{-1}**	**1500 kg·ha^{-1}**	
Al-Rafidain	1368.7^{g-k}	1645.0^{e-j}	1904.3^{d-h}	1645.3^{c}
Baytim	1212.3^{jk}	2170.0^{cde}	1445.3^{f-k}	1609.2^{c}
Local	1046.0^{k}	2019.3^{def}	1329.0^{h-k}	1464.8^{cd}
Had	1345.3^{h-k}	1853.3^{d-h}	1727.0^{d-j}	1641.9^{c}
Giza	962.7^{k}	2138.7^{cde}	1820.3^{d-i}	1640.6^{c}
COLMMUROS	1779.0^{d-j}	2914.3^{ab}	2293.0^{cd}	2328.8^{b}
Malaysian Black	1343.7^{h-k}	2012.0^{def}	1499.7^{f-k}	1618.4^{c}
NAGHAL 157	1015.0^{k}	1461.3^{f-k}	1217.7^{jk}	1231.3^{d}
Summer	1268.3^{ijk}	1673.7^{e-j}	1385.0^{g-k}	1442.3^{cd}
Wadaa	1927.3^{d-g}	3482.0^{a}	2653.7^{bc}	2687.7^{a}

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Average Sulfur Levels	1328.6^{c}	2136.9^{a}	1727.5^{b}	
*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.				

Oil percentage traits:

The oil percentage table results show significant differences between genotypes, as well as between sulfur levels, in addition to a significant interaction between the two factors. This indicates a difference in the genetic response of the genotypes to sulfur fertilization with respect to oil accumulation in seeds. The 1500 kg ha^{-1} level recorded the highest average at 50.6%, followed by the 750 kg ha^{-1} level with an average of 47.6%, while the treatment without sulfur addition recorded the lowest average at 45.7%. This reflects the important physiological role of sulfur in oil formation pathways. Sulfur is an essential element in the formation of sulfur-containing amino acids and enzymes involved in photosynthesis and fatty acid synthesis, leading to increased efficiency in converting photosynthetic products into oil stored in seeds. Improving the availability of macronutrients, particularly nitrogen, contributes to enhanced nutritional balance within the plant, which positively impacts oil content [12,14] .

The results also showed a significant interaction between plant structures and sulfur levels. The interaction between the COLMMUROS structure and a fertilizer level of 1500 kg ha^{-1} recorded the highest value at 51.4%, while the interaction between the Bytem structure and a zero fertilizer level recorded the lowest value at 44.9%. This variation indicates that plant structures respond differently to sulfur levels depending on their physiological and genetic capacity for fatty acid synthesis and oil accumulation in seeds [7]. The results indicate that moderate sulfur levels resulted in the highest average oil content compared to high levels, demonstrating that increasing sulfur levels does not necessarily lead to a sustained increase in oil content. The response depends on the genetic makeup's ability to utilize the element efficiently. [6] noted that moderate sulfur levels are often more efficient at improving seed quality, including oil content, compared to high levels.

Furthermore, some varieties exhibited excelled oil content regardless of sulfur levels, reflecting a higher genetic predisposition for oil accumulation in seeds. This excelled is attributed to differences in the physiological efficiency of these varieties in directing photosynthetic products towards oil synthesis rather than other components. These findings are consistent with those of [4, 8]who emphasized that genetic variation is a crucial factor in determining oil content in oilseed crops.

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Table (7) Arithmetic means of the effect of sulfur levels, compositions and the interaction between them on the oil percentage traits

genotype	Sulfur levels			average genotype
	Zero	750kg·ha⁻¹	1500kg·ha⁻¹	
Al-Rafidain	46.6^{h-k}	47.0^{hij}	49.5^{c-f}	47.7^{a}
Baytim	44.9^{l}	48.1^{e-g}	49.7^{b-e}	47.5^{a}
Local	44.9^{l}	47.8^{ghi}	50.9^{abc}	47.8^{a}
Had	45.8^{jkl}	47.1^{hij}	50.6^{abc}	47.8^{a}
Giza	45.8^{jkl}	47.8^{ghi}	50.6^{abc}	48.0^{a}
COLMMUROS	46.0^{jkl}	48.0^{fgh}	51.4^{a}	48.5^{a}
Malaysian Black	45.1^{kl}	47.1^{hij}	51.3^{ab}	47.8^{a}
NAGHAL 157	46.0^{jkl}	47.2^{hij}	51.0^{abc}	48.1^{a}
Summer	45.7^{jkl}	47.0^{hij}	50.9^{abc}	47.9^{a}
Wadaa	46.3^{i-l}	48.9^{c-f}	50.1^{a-d}	48.4^{a}
Average Sulfur Levels	45.7^{c}	47.6^{b}	50.6^{a}	

*Means for factors sharing the same letter and their interaction do not differ significantly according to Duncan's multiple range test at a probability level of 0.05.

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