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Original Research Article

Effect of Agricultural Sulfur Fertilization on Six Barley Varieties (*Hordeum vulgare* L.) under the Conditions of Salah Al-Din Governorate

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Abstract: A field experiment was conducted in Al-Mu'tasim subdistrict, Samarra district, Salah al-Din Governorate, during the 2024-2025 winter growing season using six barley varieties (Arevat, Normar, Jazira-120, Cleaber, Local Black Barley, and Baghdad-1) and three levels of agricultural sulfur (0, 500, and 1000 kg S ha^{-1}). The experiment was designed according to a randomized complete block design (RCBD) with three replications. The results showed that increasing the sulfur level led to a significant improvement in most growth and yield characteristics. The high application level (1000 kg ha^{-1}) resulted in the highest average plant height (93.2 cm), shoot dry weight (5.12 g plant^{-1}), number of spikes (4.5 spikes plant^{-1}), number of grains spike (46.70 grains), 1000-grain weight (50.32 g), total grain yield (4189 kg ha^{-1}), and biological yield (7642 kg ha^{-1}), in addition to the highest grain protein concentration (12.16%), compared to the no-application treatment, which recorded the lowest values for all studied traits. The varieties also showed significant variation in their response. The Jazira-120 variety had the highest total grain yield (4271 kg ha^{-1}), while the Baghdad-1 variety recorded the highest biological yield (7783 kg ha^{-1}), and the Local Black Barley variety recorded the lowest values for most traits. Interaction analysis confirmed a significant effect between sulfur levels and varieties, with some varieties, particularly Jazira-120 and Baghdad-1, achieving the best performance at the highest application level.

Keywords: Agricultural sulfur, barley, genetic makeup, Salah al-Din Governorate.

INTRODUCTION

A major grain crop grown all over the globe, barley (Hordeum vulgare L.) is used to make drinks, animal feed, and human nourishment. Among the culinary businesses that use it are juices, health foods, and alcoholic drinks. Barley is a perfect crop to grow in Iraq and other regions with little water resources since it can withstand severe weather conditions including drought, salt, and high temperatures [1]. Additionally, barley's comparatively short growing season allows for crop rotation and many growing seasons, which enhances the sustainability of agricultural production and increases land use efficiency.

During the 2023–2024 season, Iraq produced over 1.4 million tons of barley, indicating the country's recent strong growth in barley farming. The rising need for feed grains to sustain livestock and provide local food security is the reason for this growth [2]. This expansion is associated with the use of improved agricultural systems, such as the selection of high-yielding local and experimental barley varieties that stand out for their resistance to common field diseases and their ability to withstand changing climatic conditions, such as extended droughts and high temperatures.

Research indicates that new and experimental barley varieties may outperform conventional kinds in terms of grain protein content, plant height, or the number of spikes per square meter. Additionally, studies show that choosing the right variety based on local climate and soil properties increases production stability and lowers yield losses under various stressors [3].

Barley development, protein synthesis, and grain quality are all significantly impacted by sulfur, an important element for plants. Essential sulfur-containing amino acids, such as cysteine and methionine, which are basic building blocks of proteins in grains and leaves, are formed in part by sulfur. Additionally, it helps produce a number of the enzymes required for photosynthesis and chlorophyll production [4]. Sulfur enhances development and grain output in barley-growing soils, according to recent research [5]. Research on the effects of sulfur on various barley types in Iraq is essential given the significance of barley in boosting local food security and its role in supporting the livestock industry. Thus, the purpose of this research was to examine how sulfur levels affected the growth, yield, and protein properties of six different types of barley.

MATERIALS AND METHODS

Study Factors

- Arevat, Normar, Jazira-120, Cleaber, Local Black Barley, and Baghdad-1 were the six varieties of barley that were used.
- Sulfur Level: Three distinct rates of 0, 500, and 1000 kg/ha of 90% foamed sulfur were applied.

Experimental Site and Land Preparation

During the autumn growing season of 2025, a field experiment was conducted in Al-Mu'tasim sub-district, Samarra district, Salah al-Din Governorate. Five randomly selected soil samples from a depth of 0 to 30 cm were collected. They were then mixed together, pounded with a wooden mallet, sieved through a 2 mm screen, and let to air dry. After that, the materials were placed in plastic containers for chemical and physical analysis (see Table 1). The experiment included randomized complete block design (RCBD) and split-plot analysis. The land was divided into three replicates, each containing eighteen experimental units, once it had been leveled and plowed. The soil was divided into 5 m^2 plots (2.5 x 2 m) with a 1 m spacing between duplicates after being leveled, smoothed, and plowed twice in perpendicular directions to prevent fertilizer from migrating between units. Each plot consisted of ten rows spaced 20 cm apart.

Fertilization and Planting

A single treatment of 200 kg P2O2 ha− of triple superphosphate (P2O2 46%) was applied during planting. 160 kg ha− of potassium fertilizer (potassium sulfate) were applied in a single application [6]. At a rate of 200 kg N/ha, nitrogen fertilizer was applied twice: once at planting and again 45 days later [7]. 120 kilogram of barley seeds were planted per acre on November 30, 2025. Crop management practices, such as hoeing, weeding, and watering, were used as needed to ensure healthy plant growth. The plants reached full maturity and were harvested on April 24, 2025.

Table 1: Physical and Chemical Properties of the Experimental Soil during the 2025 Growing Season

Property	Unit	Value
Soil pH	–	7.62
Electrical Conductivity (EC)	dS m^{-1}	2.89
Organic Matter	g kg^{-1}	0.85
Available Nitrogen	mg kg^{-1}	19.15
Available Phosphorus	mg kg^{-1}	8.24
Available Potassium	mg kg^{-1}	125.23
Sand	g kg^{-1}	522
Silt	g kg^{-1}	229
Clay	g kg^{-1}	249
Soil Texture	–	S.C.L (Silty Clay Loam)
Gypsum	g kg^{-1}	32
Calcium Carbonate ($CaCO_3$)	%	20.21

Soil analysis was conducted at the Laboratory of the College of Agriculture, Department of Soil and Water Resources, University of Tikrit.

Characteristics Studied

- **Plant Height (cm):** Measured from the soil surface to the tip of the main spike, excluding the awns, using five randomly selected plants from each experimental unit.
- **Plant Dry Weight (g $plant^{-1}$)**: Ten plants were taken from each experimental unit, cut near the soil surface, washed with distilled water to remove dust and debris, air-dried for a short time, and then placed in an

electric oven at 70°C until the weight stabilized. The average weight was then calculated.

- **Number of Spikes (spikes plant^{-1})**: The number of spikes was calculated from the average of ten plants taken from the midlines of each experimental unit.
- **Number of Grains spike (grain-spikes)**: Ten randomly selected spikes were taken from each experimental unit, threshed manually, and the total number of grains was calculated and divided by 10 to obtain the average number of grains spike.
- **Weight of 1000 grains (g)** :1000 grains were randomly selected using a seed counter at 12% moisture content and weighed using a sensitive balance. The process was repeated three times to calculate the average.
- **Grain yield (kg ha^{-1}):** After manually threshing the harvested plants from one square meter of each experimental unit and separating the chaff from the seeds, the grains were weighed. The weight of the grains extracted from ten spikes was added to calculate the number of grains per unit, and then the weight was converted to tons/ha.
- **Biological yield (kg ha^{-1}) :** The barley plants were harvested after full maturity from one square meter of each experimental unit, then weighed, and the average was calculated for each unit.
- **Protein concentration in grains(%) :** The nitrogen content in the seeds was calculated using a Kjeldal macrometer, and then the equation was applied: % protein = % nitrogen × 6.25 [8].

Statistical Analysis

The data were analyzed using a randomized complete block design (RCBD), with results compared using the least significant difference (LSD) at the 0.05 level. Statistical analysis was performed using Excel and SAS V9 software [9].

RESULTS AND DISCUSSION

- **Plant Height (cm)**

The results in Table (2) show that the application levels of agricultural sulfur had a significant effect on barley plant height. The highest average height was recorded at the 1000 kg ha^{-1} application level (93.2 cm), followed by the average 500 kg ha^{-1} level (85.3 cm). The lowest average height was recorded in the no-application treatment (76.6 cm). This is attributed to the important physiological role of sulfur in the formation of sulfur-containing amino acids such as cysteine and methionine, and its involvement in protein and enzyme synthesis, which enhances cell division activity, cell elongation, and improves plant height [10].

The results also showed significant differences in plant height among barley varieties. The Cleaber variety recorded the highest average height (91.3 cm), not significantly different from the Normar variety (87.3 cm), while the Local Black Barley variety recorded the lowest average height (78.8 cm). This is attributed to differences in genetic traits and nutrient uptake efficiency [11].

The results of the interaction between sulfur levels and varieties showed a significant effect. The highest height for the Cleaber variety was at the 1000 kg level (99.1 cm), while the same variety recorded 83.5 cm at the no-sulfur level. The lowest height was recorded for the Local Black Barley variety at the 500 kg level (72.5 cm). This indicates that the combination of a suitable genetic variety and a high sulfur level provides a favorable nutrient environment to promote vegetative growth, while an average level may lead to a lower nutrient supply for some varieties, thus limiting their growth.

Table 2. Effect of sulfur level on plant height for six barley varieties (cm)

Barley varieties	Agricultural sulfur (kg ha^{-1})			Mean of varieties
	0	500	1000	
Arevat	75.2 f	86.1 d	95.5 a	85.6 b
Normar	76.4 f	88.3 c	97.2 a	87.3 a
Jazira-120	74.1 f	82.7 e	89.4 c	82.1 c
Cleaber	83.5 e	91.2 b	99.1 a	91.3 a
Local Black Barley	72.5 g	78.3 f	85.6 d	78.8 d
Baghdad-1	77.3 f	85.2 d	91.7 b	84.7 b
Mean of sulfur levels	76.6 c	85.3 b	93.2 a	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	3.1	3.4	5.6	

- **Dry weight of the vegetative parts (g plant^{-1})**

The results in Table (3) show that agricultural sulfur levels had a significant effect on the dry weight of the vegetative parts of six barley varieties. The highest average dry weight was recorded at the high sulfur application level (1000 kg ha^{-1}) at 5.12 g, while the average decreased to 4.61 g at the (500 kg ha^{-1}) level, and the lowest average was recorded at 4.07 g at the no-sulfur application level (0 kg ha^{-1}). This improvement in dry weight with increasing sulfur is attributed to the vital physiological role of sulfur in plants, as it contributes to the formation of sulfur-containing amino acids such as cysteine and methionine, which are involved in the synthesis of proteins and enzymes. This, in turn, promotes cell division and cell elongation, increasing the accumulation of plant dry mass and enhancing vegetative growth [12].

The results also showed significant differences between varieties. Jazira-120 recorded the highest average dry weight (5.12 g), followed by Baghdad-1 (4.79 g), while Local Black Barley recorded the lowest average (4.15 g). This variation reflects genetic differences between varieties in their ability to convert absorbed nutrients into biomass, as well as their efficiency in responding to different sulfur levels, a finding confirmed by researchers in their previous studies on barley varieties [11].

The interaction analysis between sulfur level and variety showed a significant effect. Jazira-120 recorded the highest dry weight (5.73 g) at the no-sulfur level, outperforming other interaction groups, while Local Black Barley recorded the lowest dry weight (3.81 g) at the 500 kg ha^{-1} level. These results indicate that the genetic characteristics of the variety play a key role in determining the efficiency of nutrient utilization under different sulfur levels. Highly efficient varieties take advantage of the high sulfur level to promote dry mass accumulation, while some varieties may not fully utilize the nutrients at intermediate levels.

Table 3: Effect of sulfur level on the dry weight of six barley varieties (g)

Barley varieties	**Agricultural sulfur (kg ha^{-1})**			**Mean of varieties**
	0	500	1000	
Arevat	4.02 f	4.58 de	5.03 bc	4.54 b
Normar	4.01 f	4.61 de	5.18 bc	4.60 b
Jazira-120	4.53 d	5.09 b	5.73 a	5.12 a
Cleaber	3.92 f	4.42 e	4.84 cd	4.39 c
Local Black Barley	3.81 f	4.12 f	4.51 de	4.15 d
Baghdad-1	4.12 f	4.83 cd	5.42 ab	4.79 a
Mean of sulfur levels	4.07 c	4.61 b	5.12 a	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	0.24	0.21	0.42	

- **Number of spikes (spikes plant^{-1})**

Table 4 shows that sulfur levels significantly affect the number of spikes per plant for six barley varieties. The average application level (0 kg ha^{-1}) resulted in the lowest average number of spikes per plant (3.4 spikes plant^{-1}), while the average increased to 4.0 spikes at the no-application level (500 kg ha^{-1}) and reached its highest average at the high application level (1000 kg ha^{-1}) (4.5 spikes plant^{-1}). This pattern indicates that sulfur promotes the formation of reproductive organs and improves spike count by supporting cell division, root elongation, and increased uptake of essential nutrients such as nitrogen, phosphorus, and potassium [13].

The results also showed significant differences between varieties, with Jazira-120 recording the highest average number of spikes per plant (4.4 spikes plant^{-1}), followed by Cleaber and Normar with averages of 4.2 and 4.0 spikes plant^{-1}respectively, while Local Black Barley recorded the lowest average (3.5 spikes plant^{-1}). These differences reflect genetic variations between varieties in the efficiency of reproductive organ development and their response to sulfur fertilization, which has been confirmed by recent studies that have indicated significant variation between barley varieties in productive traits such as number of spikes, plant height, and grain weight [14].

The interaction between sulfur level and variety showed a significant effect. Jazira-120, at the high application level (1000 kg ha^{-1}), recorded the highest number of spikes (5.0 spikes plant^{-1}), while Local Black Barley, at the medium application level (0 kg ha^{-1}), recorded the lowest (3.0 spikes plant^{-1}). This indicates that the response to sulfur fertilization depends on the genetic characteristics of each variety, and that combining the appropriate variety with the optimal sulfur level provides an ideal nutrient environment for the formation of a greater number of spikes per plant.

Table 4. Effect of Sulfur Level on Number of Spikes for Six Barley Varieties (spikes plant^{-1})

Barley varieties	Agricultural sulfur (kg ha^{-1})			Mean of varieties
	0	500	1000	
Arevat	3.3 C	3.8 C	4.2 BC	3.8 B
Normar	3.3 C	4.1 BC	4.6 AB	4.0 B
Jazira-120	3.8 BC	4.5 B	5.0 A	4.4 A
Cleaber	3.5 C	4.3 BC	4.8 AB	4.2 A
Local Black Barley	3.0 D	3.5 D	4.0 C	3.5 C
Baghdad-1	3.4 C	4.1 BC	4.5 AB	4.0 B
Mean of sulfur levels	3.4 C	4.0 B	4.5 A	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	0.18	0.15	0.30	

- **Number of grains spike (grains spike^{-1})**

Table (4) shows that sulfur levels have a significant effect on the number of spikes per plant for six barley varieties. The lowest average per plant was recorded at the no-apply level (0 kg ha^{-1}), with 41.06 **grains spike^{-1}**. This average increased to 43.94 grains spike^{-1} at the medium application level (500 kg ha^{-1}), and reached its highest average at the high application level (1000 kg ha^{-1}), with 46.70 grains spike^{-1}. This is attributed to the fact that sulfur promotes the formation of reproductive organs and improves spike count by supporting cell division, root elongation, and increased absorption of essential nutrients such as nitrogen, phosphorus, and potassium, which in turn affects the number of grains [13].

The results also showed significant differences between varieties, with Jazira-120 recording the highest average of 43.89 grains, while Local Black Barley recorded the lowest average of 40.82 grains spike^{-1}. These differences reflect genetic variations between varieties in the efficiency of reproductive organ development and their response to sulfur fertilization. This was confirmed by recent studies that indicated significant variation among barley varieties in productive traits such as number of spikes, plant height, and grain weight [14].

The results of the interaction between sulfur level and variety showed a significant effect, with the highest number of spikes per plant observed in Jazira-120 at the high application level (1000 kg ha^{-1}, with an average of 46.42 grains spike), and the lowest number observed in Local Black Barley at no application level (with an average of 40.86 grains spike^{-1}).

Table 5. Effect of sulfur level on the number of grains spike for six barley varieties (grain spike^{-1})

Barley varieties	Agricultural sulfur (kg ha^{-1})			Mean of varieties
	0	500	1000	
Arevat	43.86 bc	46.58 ab	48.92 a	46.45 a
Normar	40.74 d	43.12 c	45.68 b	43.18 b
Jazira-120	41.28 cd	43.96 bc	46.42 ab	43.89 a
Cleaber	39.62 e	41.98 d	44.36 c	41.99 c
Local Black Barley	38.48 f	40.86 e	43.12 c	40.82 d
Baghdad-1	42.36 c	45.12 b	47.68 ab	45.05 b
Mean of sulfur levels	**41.06 c**	**43.94 b**	**46.70 a**	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	1.65	1.42	2.85	

- **Weight of 1000 grains (g)**

Table 6 shows that sulfur levels have a significant effect on the weight of 1000 grains for the six barley varieties. The highest sulfur application level (1000 kg ha^{-1}) resulted in the highest average weight of 1000 grains (46.70 g), significantly exceeding the average application level (43.94 g) and the no application level (41.06 g). This increase can be explained by improved nitrogen absorption of sulfur and the formation of proteins related to grain structure, in addition to sulfur's role in increasing the efficiency of nutrient utilization during grain formation [16]. Sulfur plays a crucial role in the formation of sulfur-containing amino acids, which positively affect grain structure and quality, resulting in higher grain weight.

The results also showed significant differences between varieties, with the Arevat variety recording the highest average weight (46.45 g), followed by the Baghdad-1 and Normar varieties with averages of 45.05 and 43.18 g, respectively, while the

Local Black Barley variety recorded the lowest average weight (40.82 g). This variation is attributed to differences in the genetic makeup of the varieties and their efficiency in utilizing nutrients during grain formation, a point highlighted in several recent studies on barley and grain production [17].

Furthermore, the interaction between sulfur level and variety was also observed. The highest sulfur level (1000 kg S ha^{-1}) resulted in the highest grain weight for most varieties, with the Arevat variety achieving 48.92 g per 1000 grains and the Baghdad-1 variety 47.68 g per 1000 grains. Conversely, the Local Black Barley and Cleaber varieties recorded the lowest average grain weights at the 500 kg S ha^{-1} application level (38.48 g and 39.62 g, respectively).

Table 6: Effect of Sulfur Level on 1000 Grain Weight for Six Barley Varieties (g)

Barley varieties	Agricultural sulfur (kg ha^{-1})			Mean of varieties
	0	500	1000	
Arevat	41.32 f	46.48 cd	51.67 ab	46.49 a
Normar	40.74 f	45.36 d	49.28 bc	45.13 b
Jazira-120	44.58 e	49.63 bc	54.82 a	49.68 a
Cleaber	38.96 g	43.74 e	47.51 cd	43.40 c
Local Black Barley	36.85 h	41.92 f	45.68 d	41.48 d
Baghdad-1	42.67 ef	47.58 cd	50.94 ab	47.06 b
Mean of sulfur levels	40.85 c	45.79 b	50.32 a	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	2.15	1.95	3.65	

- **Total Grain Yield (kg ha^{-1})**

Table (7) shows that different sulfur levels had a significant effect on the total grain yield of the six barley varieties. The highest sulfur application level (1000 kg S ha^{-1}) resulted in the highest average total yield of 4189 kg ha^{-1}, significantly surpassing the medium application level (4052 kg ha^{-1}) and the no application level (3630 kg ha^{-1}). This is attributed to the role of sulfur in enhancing plant metabolic processes, such as improving nitrogen uptake and the formation of sulfur-containing proteins, which positively impacts plant growth and grain formation [18].

When comparing varieties, a significant difference in total grain yield was observed. The Jazira-120 variety recorded the highest average total yield (4271 kg ha^{-1}), followed by the Baghdad-1 and Arevat varieties with averages of 4079 and 4055 kg ha^{-1}, respectively. The Local Black Barley variety recorded the lowest average yield (3613 kg ha^{-1}). These differences reflect genetic variations among varieties in their ability to utilize nutrients and form grains, which aligns with the findings of recent studies confirming that the genetic characteristics of varieties control their response to fertilization factors [5].

Regarding the interaction between sulfur level and variety, the results showed that applying a high level of sulfur (1000 kg ha^{-1}) to high-yielding varieties such as Jazira-120 and Arevat resulted in the highest total grain yield, while lower-yielding varieties such as Local Black Barley and Clearer benefited to a lesser extent. This interaction indicates that the response of total grain yield to sulfur depends on the combination of variety and nutrient level, highlighting the importance of selecting appropriate varieties when implementing sulfur fertilization programs to improve overall productivity.

Table 7: Effect of sulfur level on total grain yield of six barley varieties (kg ha^{-1})

Barley varieties	Agricultural sulfur (kg ha^{-1})			Mean of varieties
	0	500	1000	
Arevat	3725 d	4153 bc	4287 b	4055 a
Normar	3619 d	4026 c	4194 bc	3946 b
Jazira-120	3896 c	4387 ab	4529 a	4271 a
Cleaber	3486 e	3864 d	3978 cd	3776 c
Local Black Barley	3327 f	3698 e	3813 de	3613 d
Baghdad-1	3724 d	4186 bc	4327 b	4079 b
Mean of sulfur levels	3630 c	4052 b	4189 a	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	215	185	365	

- **Biological Yield (kg ha^{-1})**

The results in Table (8) indicate that the addition of agricultural sulfur led to a significant increase in the biological yield of barley compared to the non-additional treatment. The average biological yield at the 1000 kg ha^{-1} application level was 7642 kg ha^{-1}, significantly higher than the 500 kg ha^{-1} application level (7150 kg ha^{-1}) and the control treatment, which recorded the lowest average at 6567 kg ha^{-1}. This trend reflects the positive role of sulfur in improving overall vegetative growth and increasing dry matter accumulation in the plant.

This is because sulfur is an essential secondary nutrient that is a component of sulfur-containing amino acids (cysteine and methionine), proteins, and enzymes. It also plays a role in activating photosynthesis and improving nitrogen utilization efficiency, leading to increased vegetative growth and biomass accumulation in the plant, which directly impacts biological yield [19].

At the varietal level, the results showed a significant variation in biological yield among barley varieties. The Baghdad-1 variety recorded the highest average yield (7783 kg ha^{-1}), followed by the Jazira-120 variety (7333 kg ha^{-1}), while the local black variety recorded the lowest average yield (6567 kg ha^{-1}). This variation is attributed to genetic differences among varieties in nutrient uptake efficiency, vegetative growth capacity, and response to sulfur fertilization, as confirmed by recent studies examining varietal differences in growth characteristics and biological yield of barley [20].

The interaction between sulfur levels and varieties also showed a significant effect on biological yield. The Baghdad-1 variety, treated at 1000 kg ha^{-1}, yielded the highest value (8300 kg ha^{-1}), while the local black variety, without sulfur addition, recorded the lowest value (6000 kg ha^{-1}). This indicates that the response of varieties to sulfur addition is not uniform, and that some varieties have a higher efficiency in utilizing added sulfur and converting it into increased vegetative growth. This highlights the importance of selecting the appropriate variety when implementing sulfur fertilization programs.

Table 8. Effect of Sulfur Level on Biological Yield of Six Barley Varieties (kg ha^{-1})

Barley varieties	**Agricultural sulfur (kg ha^{-1})**			**Mean of varieties**
	0	500	1000	
Arevat	6800 d	7550 bc	7900 b	7417 b
Normar	6500 d	7300 c	7600 bc	7133 b
Jazira-120	6750 d	7450 c	7800 b	7333 a
Cleaber	6250 e	6950 d	7250 cd	6817 c
Local Black Barley	6000 f	6700 e	7000 de	6567 d
Baghdad-1	7100 c	7950 ab	8300 a	7783 a
Mean of sulfur levels	**6567 c**	**7150 b**	**7642 a**	
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	310	270	520	

Protein Concentration in Grains(%)

The results in Table (9) indicate that sulfur fertilization levels had a significant effect on protein concentration in barley grains. The application of 1000 kg ha^{-1} of sulfur resulted in the highest average protein concentration of (12.16%), significantly exceeding the 500 kg ha^{-1} level (11.65%) and the no-application treatment (11.08%). This significant increase is attributed to the vital role of sulfur in the formation of sulfur-containing amino acids (cysteine and methionine), which are essential components in plant protein synthesis, as well as its role in improving nitrogen metabolism within the plant. [21]. confirmed that sufficient sulfur availability promotes protein deposition in cereal grains, particularly barley.

The results showed significant differences in protein concentration among the barley varieties. The Cleaber variety recorded the highest average protein concentration (12.62%), which was not significantly different from the Baghdad-1 variety (12.42%), while the Normar variety achieved the lowest average protein concentration (11.52%). This variation reflects differences in genetic and physiological characteristics among the varieties, particularly in the efficiency of sulfur and nitrogen uptake and assimilation within the plant. These results are consistent with [22].

The interaction between sulfur level and variety had a significant effect on protein concentration. The interaction treatment of the Cleaber variety at a level of 1000 kg sulfur ha^{-1} resulted in the highest protein concentration (12.62%), which was not significantly different from the Baghdad-1 treatment at the same level (12.42%). In contrast, the Normar variety showed the lowest interaction at the no-sulfur level (10.53%), significantly outperforming all sulfur-added treatments. This significant superiority of high sulfur-level interactions is explained by the ability of some varieties to utilize added sulfur more effectively in enhancing protein synthesis within the grains, compared to less efficient varieties.

Table 9. Effect of Sulfur Level on Protein Concentration of Six Barley Varieties (%)

Barley varieties	**Agricultural sulfur (kg ha^{-1})**			**Mean of varieties**
	0	500	1000	
Arevat	11.05 C	11.63 B	12.12 A	12.12 A
Normar	10.53 D	11.05 C	11.52 B	11.52 B
Jazira-120	10.85 D	11.41 C	11.95 B	11.95 B
Cleaber	11.52 B	12.10 A	12.62 A	12.62 A
Local Black Barley	11.23 C	11.82 B	12.35 A	12.35 A
Baghdad-1	11.31 C	11.90 B	12.42 A	12.42 A
Mean of sulfur levels	11.08 C	11.65 B	12.16 A	12.16 A
L.S.D $_{0.05}$	**varieties**	**sulfur**	**varieties × sulfur levels**	
	0.25	0.20	0.40	

CONCLUSIONS

1. Sulfur plays a key role in promoting vegetative growth and increasing the quantitative and qualitative yield of barley.
2. Varieties respond to sulfur depending on their genetic traits and nutrient uptake efficiency.
3. Combining the appropriate variety with a high sulfur level achieves maximum yield.

Recommendations:

1. A sulfur level of 1000 kg ha^{-1} is recommended to improve barley growth and yield in similar soils.
2. Selecting high-efficiency varieties such as Jazira-120 and Arevat increases yield benefits.
3. Further research is needed to investigate the interaction between sulfur and the quality of irrigation or tillage water.

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