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Response of pea (*Pisum sativum*) to the application of sulfur and iron under new reclaimed land conditions

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ABSTRACT

The study explored the influence of different rates of sulfur and iron application on pea plants (*Pisum sativum*). An experiment was carried out on the farm of the National Research Centre of Research and Production in Nubaria district, Behira Governorate (Egypt) during the consecutive winter seasons of 2019/2020 and 2020/2021. Sulfur micronized was applied in varying quantities (Zero, 40, 80 and 120 kg fed^{-1}) during soil preparation, while chelated iron was sprayed on the plants at concentrations of Zero, 50, 100 and 150 ppm on days 30 and 45 after planting. The data collected revealed that both sulfur and iron application had significant positive effects on chlorophyll content, plant biomass production, yield, and Macronutrient, calcium (Ca) content as well as micronutrients in both shoots and pods. Moreover, the nutritional quality of the pods, expressed in terms of protein and carbohydrate content, showed a favorable response to these treatments. The interaction between the two nutrients (sulphur at 80 kg fed^{-1} with the foliar spray Fe at 150 ppm) also had a significant impact on the growth and production of the pea plants followed by the interaction between sulphur at 80 kg fed. with the foliar spray Fe at 100 ppm. Specifically, the plants treated with sulfur and iron displayed higher chlorophyll content, suggesting a more efficient photosynthetic process. Furthermore, these plants exhibited greater biomass and a higher number and weight of pods compared to the control group. The effects of applying both nutrients appeared to be cumulative.

Keywords: Pea - Sulfur - Iron – Growth – Nutrient content.

INTRODUCTION

Pea plants, (*Pisum sativum*), are extensively cultivated for their nutritious pods and seeds. The cultivation of this crop plays a significant role in improving food security and reducing malnutrition across various populations worldwide. Based on statistics from the Food and Agriculture Organization (FAO), green peas are grown in a total area of 2,618,097 hectares, yielding 20,945,188 tons (FAO stat, 2022). Given its importance, it becomes crucial to enhance the growth and productivity of pea plants through the implementation of different agricultural practices, particularly the application of essential nutrients like sulfur and iron, especially in calcareous and infertile soils.

Sulfur, being a vital macronutrient, plays various roles in plant metabolic processes, such as amino acid and protein formation, as well as chlorophyll synthesis. Sulphur is essential for various biological processes, including photosynthesis, energy production, photoprotection, and metabolic reactions, and isa crucial component of compounds like iron-Sulphur cluster-containing proteins (Yadav *et al.,* 2021). Sulphur plays vital roles in the fundamental processes of plant metabolism, providing essential antioxidant and protective functions against various environmental stresses. As we confront the growing global demands for food, animal feed, and biofuels to support an increasing population, Sulphur, much like other macronutrients, can play a pivotal role in promoting sustainable soil fertility management, enhancing crop yields, and producing nutrient-rich crops (Dawar *et al.,* 2023).

The application of iron chelates or iron-based fertilizers has been proven effective in combating iron deficiency and enhancing pea plant growth. Iron supplementation leads to improved chlorophyll content, increased photosynthetic rates, and overall plant development (Devi *et al.,* 2017). Leaf chlorosis could be caused by the deficiency of nitrogen, potassium, magnesium or iron in diverse species, but the mechanism might be different (de Bang *et al.,* 2020). On the other hand, excessive sulfur and iron have negative effects on pea plants. High levels of sulfur can modify plant reactions to herbicide treatment and induce or aggravate nutrient disorders. It can inhibit shoot and root biomass growth and decrease chlorophyll and carotenoid content (Nenova, 2009). As the fundamental food source for animals and human beings, plants can directly absorb iron nutrition from the soil environment and are direct carriers of iron received from the soil (Krishna *et al.,* 2023). Similarly, excessive iron supply, ranging from deficiency to toxicity, can decrease shoot and root growth, alter chlorophyll and carotenoid content, and affect photosynthetic indices. Therefore, it is crucial to find the right balance when applying these nutrients to pea plants. Therefore, this study aims to determine the optimal balance of sulfur and iron application rates to pea plants to improve their growth and productivity.

MATERIAL AND METHODS

Experimental procedures:

A field experiment was conducted during the consecutive winter seasons of 2019/2020 and 2020/2021 at the Agricultural Experimental Station of the National Research Centre, Nubaria, Behira Governorate, Egypt. The primary objective was to examine the impact of applying micronized sulfur along with iron through foliar application on the growth, yield, and chemical composition of pea plants cultivated in sandy soil conditions. The initial properties of the soil presented in (Table 1) were determined through soil analyses, following the methodology outlined by (Rebecca, 2004).

Table 1. Soil characteristics of the experimental plot in Nubaria experimental farm (data average two seasons).

Soil texture (sandy)			OM	$CaCO_3$	pH	EC	Available nutrient (mg/kg)		
Sand	Silt	Clay	%	%	(1:2.5)	(1:5)	N	P	K
87.1%	5.51%	7.11%	0.62	1.63	7.35	0.92 dS m^{-1}	12.8	8.14	102.8

The experimental soil was fertilized before sowing with the recommended dose of fertilizers, as specified by the ministry of Agriculture, including 50 kg fed^{-1} of amonium sulphate (20%N), 100 kg fed^{-1} of super phosphate (15.50% P_2O_5), and 50 kg fed^{-1} of potassium sulphate (48% K_2O). The seeds of green pea (*P. sativum*) cv. Progress 9 were sown in the soil on the designated dates in two different seasons (Which were planted on October 15 and 16 during the two years, respectively), with 30 cm distance between plants and 60 cm between rows. To provide the necessary water, a drip irrigation system was utilized. The experiment was conducted using a split-plot design, with three replicates. The main plots were assigned different levels of sulfur, while the sub-plots received various iron foliar treatments. This experiment included 16 treatments which were the combinations between 4 rates of micronized sulfur and 4 concentations of chelated iron . The sulfur rates included 40, 80, and 120 kg fed^{-1} were added during soil preparation, while foliar fertilization treatments of iron (0, 50, 100, and 150 ppm) were sprayed at 30 and 45 days after sowing.

Measurements:

The chlorophyll content was measured using the Minolta-SPAD Chlorophyll Meter (Minolta Camera Co., Osaka, Japan). The SPAD-502 chlorophyll meter assesses the absorbance of chlorophyll in the red and near-infrared wavelengths and calculates a numerical SPAD value that correlates with the amount of chlorophyll present in the leaf (Minolta, 1989). To assess the yield and its components, samples were collected from 50 randomly chosen plants in each experimental unit at the stage when the green pods are marketable after 80 days from sowing. These samples were used to estimate the average fresh weight of pods and shoots, and to record the following data:

- **Average number of pods/plant** = Number of pods per plot/ Number of plants per plot
- **Green pod yield**/ feddan (it was calculated as sum of all harvests per plot, then converted to yield/ feddan).
- **Harvest index:** HI =pod yield / biological yield into 100.

Nutrient content analysis:

The plant's N, P, K, Ca, and Mg content was estimated by digesting 0.2 g of dried leaf and seeds with sulfuric acid and H_2O_2. After diluting the mixture with distilled water, the samples were analyzed for their nutrient content (macro – micronutrient) using the method described by (Cottenie, 1982). To determine the total carbohydrate content, the colorimetric method described by (Dubois *et al.,* 1956) was employed. The crude protein percentage was determined using the Macro-Kjeldahl method as outlined by (A.O.A.C., 1990). To calculate the total crude protein value, the total N values were multiplied by a factor of 6.25.

Statistical analysis:

The means of data recorded were subjected to the analysis of variance according to (Snedecor and Cochran, 1980). The Least Significant Differences (LSD) at P=0.05 level was used to verify the differences among means of the treatments.

RESULTS

Growth parameters:

The impact of sulfur application on the overall chlorophyll content can be seen in (Table 2). The effect of sulfur application was clearly positive and significant, the pod fresh and dry weights responded positively and significantly to the sulfur application rates.

Table 2. Chlorophyll content, fresh, dry weight pods and shoot affected by sulphur and iron foliar application (data average two seasons).

Sulphur levels	Iron levels	Total Chlorophyll	Fresh weight (g plant^{-1})		Dry weight (g plant^{-1})	
			Pods	Shoot	Pods	Shoot
0 (kg fed^{-1})	Zero Fe	34.36p	21.8p	12.95p	4.55p	2.49p
	Fe 50 ppm	37.42l	23.99l	13.85l	5.14l	2.71l
	Fe 100 ppm	43.43h	27.84h	17.3h	5.57h	3.31h
	Fe 150 ppm	46.42d	28.8d	18.44d	6.26d	4.29d
40 (kg fed^{-1})	Zero Fe	36.41o	23.16o	13.24o	4.97o	2.61o
	Fe 50 ppm	39.68k	24.26k	14.51k	5.26k	2.82k
	Fe 100 ppm	46.46g	28.22g	17.13g	6.04g	3.44g
	Fe 150 ppm	49.4c	30.08c	19.65c	6.76c	4.36c
80 (kg fed^{-1})	Zero Fe	41.66n	24.67n	15.79n	5.17n	2.95n
	Fe 50 ppm	42.71i	26.18i	16.48i	5.74i	3.17i
	Fe 100 ppm	50.97e	31.63e	18.84e	7.13e	4.54e
	Fe 150 ppm	54.67a	34.75a	20.18a	7.54a	5.06a
120 (kg fed^{-1})	Zero Fe	41.98m	25.34m	16.32m	5.41m	3.14m
	Fe 50 ppm	47.71j	28.63j	17.5j	6.48j	4.31j
	Fe 100 ppm	51.2f	31.69f	20.06f	7.06f	4.57f
	Fe 150 ppm	53.34b	33.42b	20.43b	7.34b	4.99b
Mean of Sulphur	0 (kg fed^{-1})	38.60d	23.74d	14.57d	5.03d	2.79d
	40 (kg fed^{-1})	41.88c	25.76c	15.58c	5.65c	3.25c
	80 (kg fed^{-1})	48.01b	29.85b	18.33b	6.45b	3.96b
	120 (kg fed^{-1})	50.95a	31.76a	19.67a	6.97a	4.67a
Mean of Iron	Zero Fe	40.41d	25.61d	15.65d	5.38d	3.2d
	Fe 50 ppm	42.98c	26.43c	16.13c	5.75c	3.32c
	Fe 100 ppm	47.50b	29.31b	17.83b	6.39b	3.93b
	Fe 150 ppm	48.56a	29.77a	18.57a	6.57a	4.25a
LSD 0.05	Sulphur	1.417	0.688	0.703	0.166	0.081
	Iron	0.482	0.634	1.264	0.342	0.130
	Interaction	2.056	1.432	2.130	0.550	0.228

It was also observed that the degree of increase from one dose to another varied. For example, increasing the application rate from 40 to 80 kg fed^{-1} resulted in a higher increment compared to moving from 80 kg fed^{-1} to 120 kg fed^{-1}. The application of iron (Fe) had a substantial and positive impact on the chlorophyll content. The interaction effect of applying sulfur and iron seemed to be cumulative on total chlorophyll content and fresh and dry weights of both pods and shoots. As the application rate of both nutrients increase, the response of the fore mentioned parameters increases significantly. Although a linear trend was clear, the increment rate showed to get lower (but still significantly positive) above 100 Fe and 80 kg sulfur treatments.

Yield production:

pod yield:

The pod yield showed a significant and positive response to sulfur application, there was no significant difference in increment between the treatment of 80 and 120 S kg fed^{-1} (Table 3). The total fresh weight of the biological yield (fresh weight of shoot and yield) also responded positively to sulfur application, but the differences between 80 and 120 kg fed^{-1} were not significant. As the rate of Fe foliar application increased, there was a significant increase in pod yield. This increase was linearly related to the application rate, with the largest increase observed at an application rate of 150 ppm (Table 3). Similarly, the total biological yield also responded significantly to the increase in Fe application, Harvest index increased as the application rate of sulfur increased, with the highest value recorded at the highest application rate. The two highest application rates of both nutrients resulted in the highest harvest index. The interaction effect of Fe and S treatments positively affected the pod yield and showed significant differences compared to the control. Surprisingly, the highest application rates of both nutrients did not show any significant difference between them. The effect of the highest rate of application of both nutrients declined.

Table 3. Yield characters of pea plant affected by sulphur and Iron foliar application (data average two seasons).

Sulphur levels	Iron levels	Pod yield (ton fed^{-1})	Shoot yield (ton fed^{-1})	Biological yield (ton fed^{-1})	Harvest Index
0 (kg fed^{-1})	Zero Fe	0.54p	0.33p	0.87p	62.08p
	Fe 50 ppm	0.58l	0.35l	0.93l	62.53l
	Fe 100 ppm	0.71h	0.41h	1.11h	63.51h
	Fe 150 ppm	0.74d	0.45d	1.19d	62.24d
40 (kg fed^{-1})	Zero Fe	0.58o	0.34o	0.92o	63.38o
	Fe 50 ppm	0.61k	0.37k	0.98k	62.48k
	Fe 100 ppm	0.73g	0.41g	1.14g	64.00g
	Fe 150 ppm	0.78c	0.46c	1.23c	62.85c
80 (kg fed^{-1})	Zero Fe	0.63n	0.39n	1.02n	61.52n
	Fe 50 ppm	0.64i	0.42i	1.06i	60.66i
	Fe 100 ppm	0.91e	0.48e	1.4e	65.31e
	Fe 150 ppm	0.98a	0.52a	1.51a	65.22a
120 (kg fed^{-1})	Zero Fe	0.63m	0.4m	1.03m	61.12m
	Fe 50 ppm	0.72j	0.43j	1.15j	62.34j
	Fe 100 ppm	0.81f	0.49f	1.3f	62.06f
	Fe 150 ppm	0.97b	0.52b	1.48b	65.21b
Mean of Sulphur	0 (kg fed^{-1})	0.59d	0.36d	0.96d	62.03c
	40 (kg fed^{-1})	0.64c	0.39c	1.03c	62.00d
	80 (kg fed^{-1})	0.79b	0.44b	1.24b	63.72b
	120 (kg fed^{-1})	0.86a	0.48a	1.35a	63.87a
Mean of Iron	Zero Fe	0.64d	0.38d	1.03d	62.59d
	Fe 50 ppm	0.67c	0.39c	1.06c	63.17b
	Fe 100 ppm	0.79a	0.45b	1.25a	63.18a
	Fe 150 ppm	0.78b	0.46a	1.24b	62.68c
LSD 0.05	Sulphur	0.029	0.007	0.027	0.036
	Iron	0.015	0.042	0.042	0.024
	Interaction	0.048	0.053	0.075	0.051

Seed yield:

Fe application rates had a positive and significant effect on both the total number of pods per plant and the weight of seeds per plant. The highest effect was observed at the highest application rate. Figure (1and 2) illustrates the total number of pods per plant and the weight of seeds per plant. Both parameters demonstrated positive responses to the interaction effect of the treatments. The highest rates application of both nutrients had the greatest impact on these parameters. However, there was a shift occured in the number of pods and weight of seeds when the Fe and S concentrations reached their highest levels. This shift was observed with a treatment of 100 ppm of Fe under 80 kg fed^{-1} of S, but a lower treatment of Fe (50 ppm) under 120 kg fed^{-1} of S.

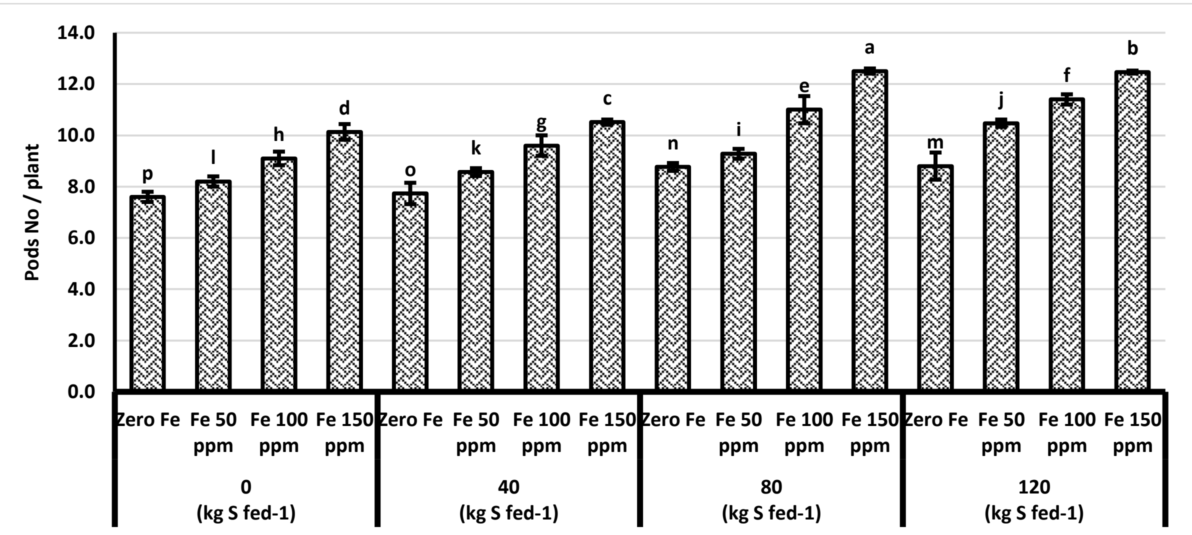

Fig. 1. Pods number /plant of pea plant affected by sulphur and iron application (data average two seasons).

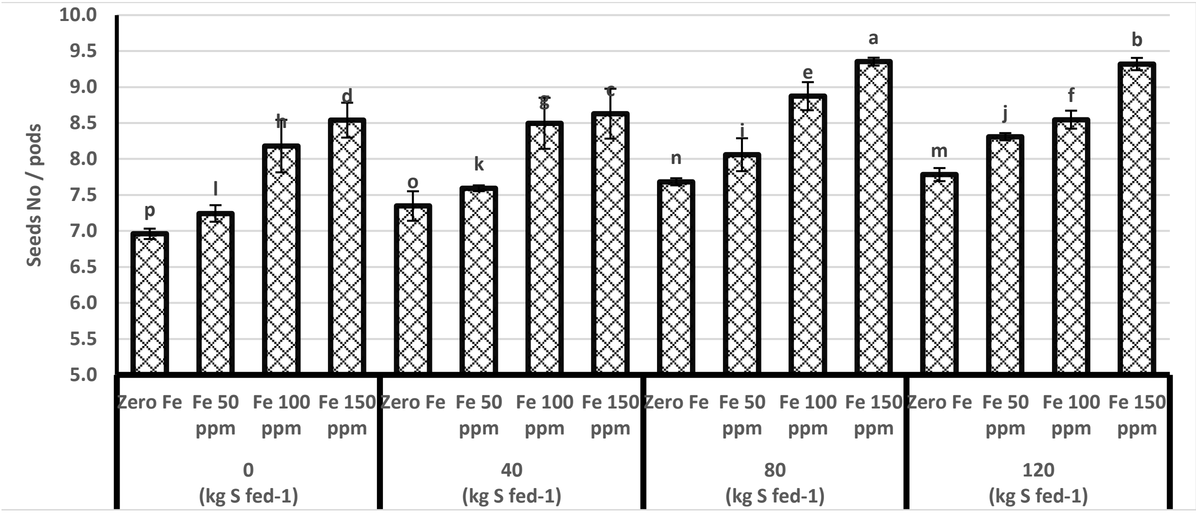

Fig. 2. Seeds number /pod of pea plant affected by sulphur and iron application (data average two seasons)

Nutrient content:

Mineral contents:

This finding suggests that the combination of iron foliar application and sulfur soil addition may synergistically affect nutrient contents in pods and shoot in terms of nitrogen, phosphorus, potassium and calcium showed significant increases compared to the control as the application rates of sulfur and iron levels increased. N, P, K and Ca contents in pods and shoots responded positively and significantly to the interaction effects. Data in (Table 4) showed that there is a significant increase in terms the N, P, K and Ca content in pods and shoots of the pea plant as a result of using sulfur at a rate of 80 kg fed^{-1}, as the increase amounted to about 12.22%, 22.19%, 8.82,15.82%, 7.18%, 11.95%, 17.65% and 7.43 % compared to the control, respectively. Data also revealed that a remarkable increase of N, P, K and Ca in pods and shoots of pea by adding sulfur at a rate of 120 kg fed$^{-1,}$ were15.48%, 29.95%, 12.16%, 15.66%, 7.38%, 14.40%, 19.12%, and 11.15% as compared with control, respectively.

Table 4. Nitrogen, phosphorus, potassium, calcium and k/ca ratioof pea plant affected by sulphur and iron foliar application (data average two seasons)

Sulphur levels	Iron levels	N (%)		P (%)		K (%)		Ca (%)	
		Pods	Shoot	Pods	Shoot	Pods	Shoot	Pods	Shoot
0 (kg fed^{-1})	Zero Fe	2.8p	1.52p	0.171p	0.133p	1.21p	1.34p	0.14p	0.64p
	Fe 50 ppm	3.04l	1.71l	0.201l	0.141l	1.26l	1.49l	0.16l	0.74l
	Fe 100 ppm	3.29h	2.02h	0.23h	0.175h	1.31h	1.58h	0.18h	0.76h
	Fe 150 ppm	3.47d	2.23d	0.237d	0.183d	1.37d	1.7d	0.2d	0.82d
40 (kg fed^{-1})	Zero Fe	2.95o	1.63o	0.197o	0.134o	1.23o	1.4o	0.16o	0.69o
	Fe 50 ppm	3.15k	1.78k	0.207k	0.144k	1.27k	1.5k	0.17k	0.74k
	Fe 100 ppm	3.41g	2.06g	0.232g	0.179g	1.33g	1.68g	0.19g	0.76g
	Fe 150 ppm	3.79c	2.13c	0.235c	0.19c	1.39c	1.79c	0.2c	0.84c
80 (kg fed^{-1})	Zero Fe	3.19n	1.94n	0.214n	0.16n	1.26n	1.52n	0.18n	0.73n
	Fe 50 ppm	3.48i	2.08i	0.219i	0.165i	1.28i	1.61i	0.19i	0.76i
	Fe 100 ppm	3.62e	2.16e	0.239e	0.191e	1.45e	1.81e	0.21e	0.81e
	Fe 150 ppm	3.85a	2.96a	0.241a	0.216a	1.53a	1.9a	0.22a	0.88a
120 (kg fed^{-1})	Zero Fe	3.31m	2.04m	0.216m	0.163m	1.27m	1.55m	0.18m	0.76m
	Fe 50 ppm	3.56j	2.26j	0.234j	0.182j	1.33j	1.76j	0.2j	0.77j
	Fe 100 ppm	3.77f	2.36f	0.24f	0.191f	1.41f	1.83f	0.21f	0.85f
	Fe 150 ppm	3.91b	3.06b	0.251b	0.195b	1.52b	1.85b	0.22b	0.91b
Mean of Sulphur	0 (kg fed^{-1})	3.03d	1.78d	0.19d	0.1475d	1.24d	1.45d	0.17d	0.71d
	40 (kg fed^{-1})	3.31c	1.96c	0.22c	0.158c	1.26c	1.59c	0.18c	0.75c
	80 (kg fed^{-1})	3.52b	2.15b	0.23b	0.184b	1.37b	1.73b	0.19b	0.79b
	120 (kg fed^{-1})	3.75a	2.60a	0.24a	0.196a	1.45a	1.81a	0.21a	0.86a
Mean of Iron	Zero Fe	3.15d	1.87d	0.22d	0.158d	1.28d	1.53d	0.17d	0.74d
	Fe 50 ppm	3.33c	1.91c	0.22c	0.162c	1.31c	1.59c	0.18c	0.76c
	Fe 100 ppm	3.54b	2.29b	0.23b	0.183b	1.36b	1.71b	0.20b	0.79b
	Fe 150 ppm	3.64a	2.43a	0.24a	0.184a	1.38a	1.75a	0.22a	0.83a
LSD 0.05	Sulphur	0.026	0.073	0.0037	0.0058	0.027	0.046	0.010	0.016
	Iron	0.029	0.122	0.0062	0.0019	0.015	0.031	0.005	0.013
	Interaction	0.059	0.211	0.0108	0.0083	0.045	0.084	0.016	0.031

Also, the data showed a cumulative effect from both nutrients by foliar application of iron levels, where there was a noticeable increase in the N, P, K and Ca in both pods and shoots achieved by application of iron at a rate of 100 ppm were 15.02%, 20.62 %, 17.92%, 24.75%, 10.66%, 18.76%, 19.70% and 12.77% as comparable with un foliar of iron, respectively. while application of iron at a rate of 150 ppm gave the highest value of the above-mentioned elements by about 22.61%, 45.58%, 20.80%, 32.88%, 16.90, 24.61, 27.27 and 22.34% as compared with control, respectively.

Carbohydrate and protein:

Regarding carbohydrates and protein (Fig. 3) describe the influence of sulfur and foliar application of micronutrient such as Fe on carbohydrates and protein. Data showed a positive and significant response to sulfur application compared to the control. The nutritional quality of the pods in terms of protein and carbohydrate content also showed positive and significant responses to the interaction effect of applied S and Fe compared to the control. The results revealed that slightly increased in quality affected by applied of sulfur levels soil adding with iron foliar spray. application of S at a rate of 80 kg fed^{-1} with the foliar spray of iron at a rate of 150 ppm gave the highest value of carbohydrates and protein. The increased levels of carbohydrates and protein in the plants could potentially lead to improved overall health and productivity. Further research could explore the mechanisms behind this interaction and how it can be optimized for agricultural practices.

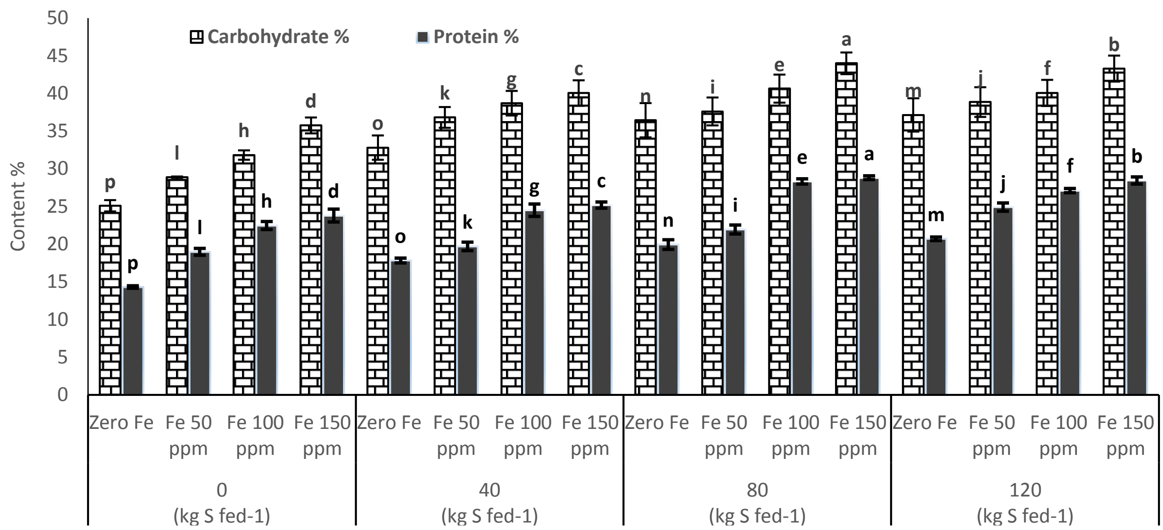

Fig. 3. Carbohydrate and protein content of pea seeds affected by sulphur and iron application (data average two seasons**)**.

Micronutrient contents:

The effect of sulfur levels added to soil with the foliar spray of iron and their interaction on micronutrient contents (Fe, Zn, Mn; Cu) in pods and shoots of pea plants is shown in (Table 6). Results indicated that the application of sulfur has a positive effect on micronutrient content at all levels. With increasing the sulfur application rates, the micronutrient contents of pods and shoots increment and the higher contents achieved by application of 80 kg fed^{-1} S comparable to the other studied levels. as the increase amounted to about 12.55%, 33.83%, 13.38%, 25.22%, 20.84%, 20.81%, 25.05%; 19.43% as compared with control, respectively. data also showed that a significantly increase of Fe, Zn, Mn & Cu in pods and shoots of pea by adding sulfur at a rate of 120 kg fed$^{-1,}$ were14.03%, 30.77%, 11.60%, 24.10%, 15.01%, 19.83%, 21.02%, and 20.66% as compared with control, respectively.

The data also indicated a synergistic effect of foliar application of iron levels on the micronutrient contents (Fe, Zn, Mn and Cu) of pea pods and shoots, increasing of the micronutrient contents of pea pods and shoots resulting from using of iron foliar spraying, as spraying at a rate of 100 ppm led to an increase estimated at 22.31%, 9.84%, 16.44%, 29.23%, 25.74%, 31.65%, 26.13%; 30.21% as comparable with un treatment of iron, respectively. while application of iron at a rate of 150 ppm gave the greatest value of the above-mentioned elements by about 27.91%, 18.65%, 23.86%, 45.35%, 45.21%, 48.74%, 36.39% and 40.97% as compared with control, respectively. The micronutrient contents increased with increasing Fe application levels. The highest Fe, Zn, Mn and Cu contents were attained after the application of sulfur combined with iron application compared with the control treatment. Micronutrients showed a positive and significant response to the interaction effect of the treatments, with the highest response observed with the highest two levels of applied S and Fe (Table 6).

Table 6. Micronutrient content of pea plant affected by sulphur and foliar application of iron (data average two seasons).

Sulphur levels	Iron levels	Fe (ppm)		Zn (ppm)		Mn (ppm)		Cu (ppm)	
		Pods	Shoot	Pods	Shoot	Ppods	Shoot	Pods	Shoot
0 (kg fed^{-1})	Zero Fe	92.3p	143.5p	25.95p	38.39p	31.35p	19.54p	2.91p	4.64p
	Fe 50 ppm	100l	151.5l	27.48l	41.65l	41.93l	20.06l	3.26l	5.45l
	Fe 100 ppm	117h	159.6h	30.03h	49.77h	45.97h	23.71h	4.02h	6.11h
	Fe 150 ppm	125.6d	165.8d	31.94d	53.54d	54.82d	27.36d	4.18d	6.55d
40 (kg fed^{-1})	Zero Fe	97.4o	147.6o	27.76o	41.34o	37.82o	19.85o	3.2o	4.97o
	Fe 50 ppm	104k	156k	28.5k	44.91k	42.17k	20.6k	3.53k	5.43k
	Fe 100 ppm	121.6g	163.4g	31.1g	50.97g	49.88g	24.3g	4.05g	6.25g
	Fe 150 ppm	127.4c	181.9c	33.14c	56.06c	56.9c	29.17c	4.29c	6.82c
80 (kg fed^{-1})	Zero Fe	106.5n	187.5n	28.38n	45.78n	45.81n	21.63n	3.7n	5.56n
	Fe 50 ppm	113.7i	200.9i	30.02i	49.96i	51.48i	23.27i	4.1i	5.85i
	Fe 100 ppm	132.3e	214.8e	34.71e	61.39e	52.69e	30.78e	4.97e	7.62e
	Fe 150 ppm	137a	227.1a	37.73a	72.47a	60.37a	33.86a	5.2a	8.14a
120 (kg fed^{-1})	Zero Fe	112.6m	193.3m	29.1m	46.9m	44.13m	21.76m	3.93m	5.75m
	Fe 50 ppm	121.3j	195.4j	31.15j	51.44j	45.58j	23.96j	4.1j	6.46j
	Fe 100 ppm	129.1f	200.2f	33.63f	60.67f	51.53f	30.19f	4.29f	7.26f
	Fe 150 ppm	132.9b	222.4b	34.91b	68.52b	58.95b	32.74b	5.07b	7.98b
Mean of Sulphur	0 (kg fed^{-1})	102.2d	167.97d	27.79d	43.11d	39.78d	20.65d	3.44d	5.23d
	40 (kg fed^{-1})	109.75c	175.95c	29.28c	46.99c	45.29c	21.97c	3.75c	5.79c
	80 (kg fed^{-1})	125.01b	184.5b	32.36b	55.7b	50.02b	27.24b	4.33b	6.81b
	120 (kg fed^{-1})	130.73a	199.3a	34.43a	62.65a	57.76a	30.78a	4.69a	7.37a
Mean of Iron	Zero Fe	108.73d	155.1d	28.85d	45.84d	43.52d	22.67d	3.59d	5.68d
	Fe 50 ppm	112.6c	162.23c	30.13c	48.32c	46.69c	23.48c	3.78c	5.87c
	Fe 100 ppm	122.37b	207.57a	32.71a	57.41a	52.59a	27.39b	4.49a	6.79b
	Fe 150 ppm	123.98a	202.83b	32.19b	56.88b	50.05b	27.16a	4.35b	6.86a
LSD 0.05	Sulphur	1.666	0.703	0.731	1.561	0.847	0.603	0.084	0.102
	Iron	2.348	1.893	0.686	1.974	3.288	0.381	0.085	0.060
	Interaction	4.347	2.812	1.534	3.827	4.478	1.066	0.183	0.175

DISCUSSION

The findings of this investigation demonstrate the positive effects of applying both Sulfur and iron to pea plants. The advantageous impacts of Sulfur on the growth, yield, and nutrient uptake of all plants including pea plants are well documented. Addition of sulfur to the soil substantially enhances shoot lengths, number of branches, leaf area, shoot dry weight, leaf pigments, leaf macronutrients (N, P, and K), seed protein, and total yields of pods and seeds (Deepti *et al.,* 2022). The present study confirms these findings. These positive effects may be attributed to the fact that Sulfur is a key component of numerous essential compounds in plant metabolism, including amino acids (cysteine and methionine), vitamins (thiamine and biotin), and coenzymes (coenzyme A and ferredoxin). These sulfur-containing compounds play a vital role in proteins synthesis, enzymes, and other biomolecules necessary for plant growth and development. The observed overall improvement of plant metabolism is interpreted in the form of improving biomass production and yield quantity and quality (Zhou *et al.,* 2018). Similar results were demonstrated by (Osman and Radi, 2012) who conducted a field experiment and found that sulfur application significantly increased the yield and seed quality of pea plants under salinity stress. They attributed this improvement to enhanced nitrogen and phosphorus uptake, as sulfur is known to positively influence nutrient assimilation and utilization in plants. Earlier results by (Youssef, 2002), demonstrated that sulfur availability positively influenced nitrogen uptake and metabolism in pea plants. This explanation can also be applied to this study as the overall nutrient contents were improved by sulfur treatments.

Likewise, the results of this study highlight the positive effects of iron application on pea plant performance. Iron application treatments improved overall plant growth attributes and production as well as nutrient contents. Several studies have reported that iron positively influences the growth and production of pea plants by supporting chlorophyll synthesis, promoting photosynthetic activity, activating essential enzymes, facilitating nutrient uptake and transport, and contributing to stress tolerance. For instance, a study conducted by (Nenova, 2009) showed that the application of iron fertilizer significantly increased the chlorophyll content, leaf area, and yield of pea plants compared to untreated control plants. Earlier, (Nenova, 2008) reported similar findings, with iron-treated plants exhibiting higher biomass accumulation, longer roots, and increased pod formation. According to these findings, higher chlorophyll content means higher assimilation rate while longer roots mean higher nutrient and water uptake and both of these processes lead to higher biomass production which was observed in this study. The results of this study leave no doubt about the role of iron supplements on improving the growth and production of pea plants. The positive interaction effects of sulfur and iron on different plant growth aspects and nutrients contents were evident in this study. Ciaffi *et al.,* (2013) demonstrated that sulfur fertilization improved the iron content in seeds, highlighting the potential interaction between sulfur and iron uptake. Sulfur application has been found to improve iron uptake and translocation within plants, leading to increased iron utilization (Zhang *et al.,* 2014). Furthermore, the presence of adequate sulfur levels in the soil can reduce the risk of iron toxicity, as sulfur helps in the detoxification process by forming less phytotoxic complexes (Devi *et al.,* 2017). The specific mechanisms underlying the interaction between sulfur fertilization and iron uptake in pea plants are complex and may involve various physiological and molecular processes. Sulfur can influence the rhizosphere pH, organic acid exudation, and root architecture, thereby affecting iron availability and uptake in the soil. Zuchi *et al.,* (2015) emphasized the intricate relationship between sulfur and iron metabolism in plants and its implications for overall plant performance and highlighted the role of sulfur in enhancing iron bioavailability and utilization and its effects on plant growth and productivity. In addition, sulfur is recognized for its role in various physiological and biochemical processes in plants, and its interaction with iron uptake can impact the overall plant growth and production. For instance, (Astolfi *et al.,* 2021) investigated the role of sulfur in enhancing iron acquisition and utilization in plants and showed that sulfur fertilization increased the expression of genes involved in iron uptake and homeostasis, leading to improved iron utilization efficiency. All these literatures mentioned above suggest that sulfur enhance iron acquisition and utilization by the plants and the two nutrients improve plant physiological process including photoassimilate production and pod setting leading to increase in overall plant biomass production and yield. The findings of our study suggest that these effects appear to be cumulative and complementary, explaining the additive effects of the two nutrients. However, excessive iron application may have detrimental effects on plants as it can reach toxic levels.

CONCLUSION

These results highlight the importance of considering multiple nutrient inputs and their interactions when developing crop fertilization strategies. The application of sulfur and iron significantly affects the growth and production of pea plants. Sulfur application improves overall plant vigor, and yield, while iron supplementation enhances chlorophyll synthesis and photosynthetic activity. The combined use of sulfur and iron ensures their optimal utilization and mitigates the risk of detrimental effects. Agricultural practices should prioritize the appropriate provision of these essential nutrients to attain maximum yield and maintain sustainable crop production. Our study recommends an application rate of 80 kg fed^{-1} of sulfur and 150 ppm of Fe for pea plants grown in sandy soil conditions. However, further research into the specific mechanisms underlying sulfur-iron interactions in pea plants would provide valuable insights for sustainable agricultural practices.

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استجابة نبات البازلاء لإضافة الكبريت والحديد في ظل ظروف الأراضي المستصلحة حديثاً

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تُزرع نباتات البازلاء على نطاق واسع لبذورها المغذية. وتلعب زراعة هذا المحصول دورًا هامًا في تحسين الأمن الغذائي. أوضحت هذه الدراسة تأثير معدلات مختلفة من إضافة الكبريت والحديد على نباتات البازلاء. حيث أُجريت تجربة في مزرعة المركز القومي للبحوث والإنتاج في منطقة النوبارية، محافظة البحيرة (مصر) خلال موسمي الشتاء المتتاليين 2020/2019 و2021/2020. تم إضافة الكبريت الميكرونى بمعدلات مختلفة (صفر- 40- 80 و120 كجم للفدان) أثناء تجهيز التربة، بينما تم رش الحديد المخلبي على النباتات بتركيزات صفر، 50، 100 و150 جزء في المليون في اليومين 30 و45 بعد الزراعة. أظهرت البيانات أن كل من تطبيق الكبريت والحديد كان له تأثيرات إيجابية كبيرة على محتوى الكلوروفيل وإنتاج الكتلة الحيوية للنباتات والمحصول ومحتوى المغذيات الكبرى والكالسيوم (Ca) وكذلك المغذيات الدقيقة في كل من البراعم والقرون. وعلاوة على ذلك، أظهرت الجودة الغذائية للقرون، المعبر عنها من حيث محتوى البروتين والكربوهيدرات استجابة إيجابية لهذه المعاملات. كان للتفاعل بين المغذيين (الكبريت عند 80 كجم للفدان مع الرش الورقي للحديد عند 150 جزء في المليون) أيضًا تأثير كبير على نمو وإنتاج نباتات البازلاء يليه التفاعل بين الكبريت عند 80 كجم للفدان. مع الرش الورقي بالحديد بتركيز 100 جزء في المليون. وبشكل أكثر تحديدًا، أظهرت النباتات المعاملة بالكبريت والحديد محتوىً أعلى من الكلوروفيل، مما يشير إلى كفاءة عملية التمثيل الضوئي. علاوة على ذلك، أظهرت هذه النباتات كتلة حيوية أكبر وعددًا ووزنًا أكبر للقرون مقارنةً بالكنترول. ويبدو أن آثار إضافة كلا العنصرين الغذائيين كانت تراكمية.

الكلمات الافتتاحية: البازلاء - الكبريت - الحديد - النمو - المحتوى الغذائي.