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(Original Article)

Comparative Faba Bean (*Vicia faba* L) Study to Reveal the Important Role of Potassium Sulfate and Cultivar in Sandy Calcareous Soil

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Abstract

Supporting calcareous soil with soil amendments is critical to promote plant growth and enhance crop productivity. The application of potassium sulfate has been well documented to have a potential role in this regard but information on the potential of varietal responses is scarce. Therefore, the current investigation was designed to test the effect of different application rates of potassium sulfate (0,210 and 420kg/ha) in the form of potassium sulfate on the growth and yield attributes of five newly released faba bean cultivars (Sakha-1, Nubaria-4, Nubaria-5, Giza 716, and Giza 843) under calcareous soil conditions. The results showed that faba bean cultivar Nubaria-5 recorded the highest value for plant growth, yield and its component traits, Also, it recorded the highest value for nitrogen, phosphorus, potassium, and sulfur percentages in the plant shoots and seeds during the winter growing seasons of 2021/2022 and 2022/2023. The cluster analysis showed that Nubaria-5 appeared in a separate group, confirming its dissimilarity to the rest of the Varieties used. In conclusion, varietal variation exists and it may be employed in conjunction with sulfur amendments in the strategy plan for enhancing faba bean crop productivity in calcareous soil.

Keywords: *Calcareous soil, New cultivars, Reclaimed soil, S-deficient, Sulfur.*

Introduction

In Egypt, the reclaimed soil is the future expansion of arable land, but it is still not yet fully productive. Soils that contain more than 10% of $CaCO_3$ cause a problem for crop production. Approximately 27-36% of the total area in Egypt is calcareous soil, where pH is high and plants suffer from low nutrient availability (Mahmoud et al. 2023). According to the soil analysis of the experimental land in the current investigation, the average $CaCO_3$ content in the different soil depths, which ranged from 0 to 60 cm, was 30.9%. In the previous study, plant length, chlorophyll a and b, carotene contents, total nitrogen, soluble protein contents, phosphorus, and potassium of pea plants cultivated in two soil types (clay and calcareous sandy soil) were greatly decreased in calcareous

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sandy soil compared to clay soil; however, the total antioxidant content was found to be higher in the calcareous sandy soil (Mahmoud *et al*. 2023).

Sulfur (S) supplement to calcareous soil is traditionally recommended. However, rational use of mineral element supplements such as sulfur is complying with the policy of sustainable crop production. Sulfur has been reported to be one of the essential macronutrients required for plant growth. It plays an important role in chlorophyll and protein synthesis (Kaya *et al*. 2020). Barłóg *et al*. (2019) and Omer *et al*. (2020) reported that sulfur dioxide emissions reduction from different industrial sources and a decrease in usage of pesticides containing S have led to a depletion of S in the soil. Treating soil with sulfur results in H_2SO_4 generation, which slightly reduces soil pH and increases the solubility of nutrients (Erdal *et al*. 2006). Under S-deficient conditions, plants suppress cell sap osmotic pressure, resulting in a limited accumulation of intracellular solutes (Kusaka *et al*. 2005). In addition to that, SO_4 is mobilized to sustain the growth of the plant, and this contribution mechanism to adjust osmotic pressure is compensated by other osmotically active molecules (Sorin *et al*. 2015). The positive impact of sulfur application on plant growth and productivity has been reported in different crops by several researchers, i.e., potato (Sanli *et al*. 2013), canola (Govahi and Saffari 2006), and maize (Kaya *et al*. 2020). Meanwhile, the optimum sulfur dose that causes the maximum positive change in plant growth varies from crop to crop. For instance, at a rate of 4 mM, the vegetative growth of onion plants was enhanced; however, application of sulfur at a rate of 8 mM delayed the vegetative growth (Chandra and Pandey, 2014). Potassium sulfate (K_2SO_4) fertilizer is mostly used for S supply (Barłóg *et al.* 2019). Furthermore, it is known that potassium (K) is considered an essential element that contributes to stomatal regulation, osmotic adjustment, and transpiration rate, resulting in enhancing water use efficiency in plants (Gonzalez-Porras *et al.* 2024).

Faba bean (*Vicia faba* L) annual global production is more than 5,5 million tons, with Egypt being one of the main producers along with China, Ethiopia, UK, and Australia (Krenz *et al.* 2023). Faba bean is a popular legume crop in Egypt, and it is considered the third main crop after wheat and maize. Planting faba beans enhances soil fertility by fixing atmospheric nitrogen, solubilizing phosphorus, and increasing plant-microbe interactions (Haq *et al.* 2022). Recently, new cultivars were released by Egyptian breeders in different regions of Egypt, including some reclaimed calcareous soil, to adapt plants to several conditions to produce a better yield and be high tolerant. The cultivated area decreased by approximately 30%, from 271,000 acres in 2000 to 81,000 acres in 2018 (Sary *et al.* 2021). Therefore, it is important to increase annual production by increasing the cultivated area (reclaiming new lands) to meet the increasing demand. However, the productivity of the new reclaimed land is limited and affected by soil fertility and water supply.

The potential of the new cultivars is not yet fully defined, especially their interaction with sulfur in calcareous soils. Additionally, different varieties may have differential responses to sulfur application. Hence, implementing strategies to enhance nutrient availability is crucial, especially in calcareous soil. So far, no research has been reported on the response of the new faba bean varieties in Egypt in calcareous soil. The present study tackled both prominent crop species and the expansion of future arable soil in Egypt. It tested the null hypothesis against existing variation among faba bean cv. potassium supplements and the main mineral element contents.

Materials and Methods

1. Plant materials

The plant materials used in the current trial consisted of five newly released cultivars: Sakha-1, Nubaria-4, Nubaria-5, 716, and 843, which were purchased from the Department of Food Legumes Research, Field Crops Research Institute, Agricultural Research Center (ARC), Giza, Egypt.

Table 1. Average monthly meteorological data of Assiut weather station during the two growth winter seasons of 2021/22 and 2022/23

Month	Temperature (C°) Max	Temperature (C°) Min	Relative Humidity %	Wind Speed km/h	Sunshine hours
2021/2022					
October	32.4	17.6	44.2	14.9	10.0
November	28.6	13.4	50.7	9.9	9.4
December	20.3	7.7	54.7	10.7	9.0
January	17.1	4.5	57.1	10.3	8.9
February	20.2	6.4	51	13.8	9.7
March	22.6	8.4	39.2	18	9.9
April	34.6	16.2	26.4	15.4	10.3
2022/2023					
October	30.2	17.6	48.8	15.7	10.0
November	25.7	12.1	51.4	12	9.4
December	22.9	9.3	57.6	9.6	9.0
January	21.1	7.1	56	10.1	8.9
February	20.2	6.1	51	11.8	9.7
March	27.1	12.1	34.3	9.9	9.9
April	31.5	15.1	25.5	14.2	10.3

Table 2. Chemical and Physical properties of the soil in the experimental site

Chemical properties

Soil depth (cm)	pH (1:1)	EC dS m^{-1} (1:1)	Soluble cations (meq / L) Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Soluble anions (meq / L) $CO_3^{--}+HCO_3^{-}$	Cl^{-}	Available Phosphorus (ppm)	Total nitrogen (%)
0 – 15	8.10	0.42	2.16	1.40	0.29	0.96	2.25	2.00	8.32	0.019
15 – 30	8.50	0.39	1.46	1.52	0.19	0.95	1.90	1.80	8.32	0.016
30 – 45	8.55	0.26	1.08	0.89	0.14	0.61	1.42	1.17	8.30	0.013
45 – 60	8.34	0.24	1.01	0.82	0.13	0.47	1.15	0.89	8.28	0.009
Mean		0.33	1.43	1.16	0.19	0.75	1.68	1.47	8.31	0.0143

Physical properties

Soil depth (cm)	Gravel (%)	Particle size distribution (%) Sand	Silt	Clay	Texture class	O.M. (%)	$CaCO_3$ (%)	Moisture content (Volumetric %) S. P.	F.C.	W.P.	A. W. (%)	*Pb* (g/cm^3)	H.C (cm/h)
0 – 15	34.5	90.9	6.7	2.4	sandy	0.39	32.2	25.2	12.5	4.9	7.6	1.57	71.2
15 – 30	30.2	90.2	6.8	3.0	sandy	0.31	33.8	23.3	10.0	4.2	5.8	1.65	60.4
30 – 45	46.6	89.4	7.4	3.2	sandy	0.28	25.4	21.7	9.5	4.0	5.6	1.75	46.8
45 – 60	46.3	89.0	7.5	3.5	sandy	0.18	32.0	23.0	11.8	4.9	6.9	1.55	73.9
Mean	39.4	89.9	7.1	3.0	sandy	0.29	30.9	23.3	10.9	4.5	6.5	1.63	63.1

O. M.: Organic matter, S.P.: Saturation percentage, F.C.: Field capacity, W.P.: Wilting point, A.W.: Available water, *Pb*: Bulk density, H.C.: Hydraulic conductivity

2. Experimental site

The field trials of Faba bean (*Vicia faba* L.) were conducted during two growing seasons, 2021/2022 and 2022/2023, at the Farm of Arab El-Awammer Research Station, ARC, Assiut, Egypt (27°17'03.3" N, 31°13 '24.4" E). Detailed monthly meteorological data during the two growing seasons are presented in Table 1. The experiments were conducted in reclaimed calcareous soil, and the physical and chemical properties are presented in Table 2.

3. Experimental design and growth conditions

The experiment was performed as a split-plot arrangement in a randomized complete block design with three replications, considering faba bean cultivars (Sakha-1, Nubaria-4, Nubaria-5, Giza-716, and Giza-843) in the main plot. Meanwhile, the second factor was potassium sulfate (0, 210 kg/ha and 420 K_2SO_4, kg/ha). The field experiment was conducted under a drip irrigation system, and the sub-plot area was 10 m^2. Uniform faba bean seeds were sown 30 cm apart on one side of each dripper and 50 cm apart among dripper lines during the fourth week of October in both seasons. After ten days of sowing seeds, the first dose was added, and the second dose was added after 45 days from the first dose. The other agriculture practices were carried out according to the faba bean extension guide, Ministry of Agriculture, Egypt.

4. Irrigation water applied (m^3/ha)

The actual amount of irrigation water (I.Ra) under the drip irrigation system during the two experimental seasons presented in Fig. 1 was calculated using the equation reported by James (1988) as follows:

$$\mathbf{I.Ra = \frac{ETc \ + LF}{Er}}$$

Where:

I.Ra = total actual irrigation water applied mm/interval

ETc = Crop evapotranspiration using Penman Monteith equation (Smith 1991).

LF = leaching factor (10 %).

Er = irrigation system efficiency (85%).

$$\mathbf{ETc = ETo \times Kc}$$

Where:

ETo = Reference evapotranspiration,

Kc = Crop coefficient (from FAO 1979).

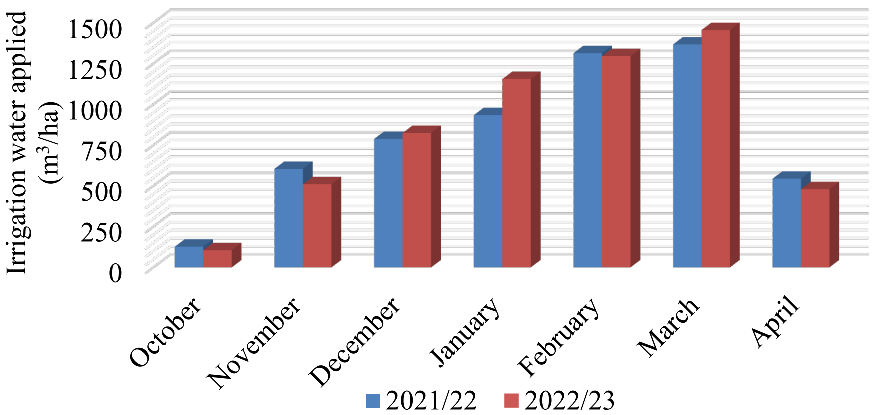

Fig. 1. Irrigation water applied (m^3/ha) for faba bean plants under a drip irrigation system in calcareous soil during the growing seasons of 2021/2022 and 2022/23

5. Growth, pod and seed yield components

At the age of 10 weeks, seven plants in each replicate were randomly used to measure plant height (cm) and the number of branches, respectively. The plot plants in each replicate were harvested during the second week of April. The traits of number of pods per plant, pod weight per plant (g), biological yield (ton/ha), seed yield (ton/ha), straw yield (ton/ha), and weight of 100-seeds (g) were recorded.

6. Cluster analysis

The cluster analysis based on phenotype and yield component data of all faba bean cultivars in response to potassium sulfate was performed using the un-weighted pair group method with arithmetic averages (UPGMA) and Bary-Curtis and constructed using the PAST 4.17 program (Hammer *et al.* 2001).

7. Irrigation water productivity (kg/m^3)

The irrigation water productivity (IWP) values were calculated using the following equation:

$$\mathbf{IWP} = \frac{\textbf{Seed yield (kg/ha)}}{\textbf{Irrigation water applied (m}^3\textbf{/ha)}}$$

8. Shoot tissues and seed contents of nutrient elements and protein

Five random plant shoots were taken from each plot after 70 days from sowing seeds, and all samples were air dried, then the oven dried at 70 ºC until a constant weight and stored until the end of the season. After harvest, 100 seeds from each plot were randomly selected and then oven-dried at 70 ºC until a constant weight was achieved. Dried samples were ground to a fine powder and approximately 50 mg was weighted, and a mixture consisting of sulfuric acid and hydrogen peroxide (Parkinson and Allen 1975) was used for sample digestion. The digested samples were used to determine nitrogen (N) using the micro-Kjeldahl method (Jackson 1973). However, total phosphorus was quantified spectrophotometrically using Fogg and Wilkinson protocols (1958), and potassium was measured by the flame emission technique (Carl-Zeiss DR LANGE M7D flame photometer, Carl-Zeiss AG, Jena, Germany) as described by

Williams and Twine (1960). Sulfur was quantified using the method reported by Bashour and Sayegh (2007). Biochemical analysis in plant shoots and seeds was determined for the varieties having the greatest and lowest productivity.

9. Statistical Analysis

An analysis of variance to determine the influences of several cultivars, potassium sulfate, and their interactions was done by MSTAT C software using combined analysis over years in accordance with the procedure reported by Gomez and Gomez (1984). The data are presented as a means, and they were separated at the P<0.05 level.

Results

1. Growth parameters

The phenotypic growth parameters (plant height and branch number) of faba bean plants in response to various rates of potassium sulfate (0, 210, and 420 kg/ha) were measured (Tables 3 and 4). The results show that the interaction between faba bean cultivars and potassium sulfate treatments significantly affected plant height. Adding potassium sulfate significantly increased plant height of all cvs (Table 3). Cultivar Nubaria-5 had the largest value of plant height among the studied cultivars. In contrast, the lowest plant height was recorded for cv Sakha-1 in all potassium sulfate treatments. However, no significant interaction between faba bean cultivars and fertilizer treatments was detected in the number of tillers per plant (Table 4). Two cvs (Sakha-1 and Nubaria-4) did not exhibit change in number of tillers per plant when received 210 kg/ha potassium sulfate as compared to 420 kg/ha potassium sulfate. Nevertheless, the other three cvs produced greater tillers when supplemented with up to 420 kg/ha potassium sulfate. Besides its superiority in plant height, cv Nubaria-5 developed the greatest overall number of tillers per plant.

Table 3. Influence of faba bean cultivars, potassium sulfate and their interactions on average plant height (cm)

Average plant height (cm)						
First season 2021/2022						
	Cultivars					
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	39.67^{B}	42.08^{B}	53.43^{A}	42.21^{B}	41.45^{B}	43.88
210 (kg/ha)	47.36^{B}	46.91^{B}	58.98^{A}	45.83^{B}	46.69^{B}	49.15
420 (kg/ha)	50.72^{B}	48.60^{B}	61.21^{A}	47.93^{B}	49.17^{B}	5152
Cultivars mean	45.91	45.86	57.87	45.33	45.77	48.15
Tukey $_{0.05}$=1.17[2]						
Second season 2022/2023						
Untreated	41.99^{B}	43.67^{B}	56.44^{A}	43.99^{B}	43.86^{B}	45.99
210 (kg/ha)	50.06^{B}	49.92^{B}	62.26^{A}	48.46^{B}	49.36^{B}	52.01
420 (kg/ha)	53.59^{B}	51.36^{B}	64.94^{A}	50.66^{B}	51.96^{B}	54.50
Cultivars mean	48.54^{b}	48.32^{b}	61.21^{a}	47.70^{b}	48.39^{b}	50.83
Tukey $_{0.05}$=1.03[2]						

[1] The means within rows followed by different letters are significantly different at P≤0.05 level of probability.
[2] Tukey's $_{0.05}$=1.17 (first season) and 1.03 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 4. Influence of faba bean cultivars, potassium sulfate and their interactions on average of tillers

Average number of tillers						
First season 2021/2022						
Cultivars						
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	3.33^{C}	4.00^{B}	5.33^{A}	4.00^{B}	3.33^{C}	4.00
210 (kg/ha)	4.33^{B}	5.67^{B}	6.67^{A}	5.00^{B}	4.67^{B}	5.27
420 (kg/ha)	4.33^{C}	5.67^{B}	7.33^{A}	5.67^{B}	5.33^{B}	5.67
Cultivars mean	4.00	5.11	6.44	4.89	4.44	4.98
Tukey $_{0.05}$=0.29[2]						
Second season 2022/2023						
Untreated	3.33^{B}	4.00^{AB}	5.33^{A}	4.67^{AB}	3.67^{B}	4.20
210 (kg/ha)	4.33^{B}	5.67^{AB}	6.67^{A}	5.33^{AB}	4.67^{B}	5.33
420 (kg/ha)	4.67^{B}	5.67^{B}	7.67^{A}	5.67^{B}	5.67^{B}	5.87
Cultivars mean	4.11	5.11	6.56	5.22	4.67	5.13
Tukey $_{0.05}$=0.27[2]						

[1] The means within rows followed by different letters are significantly different at $P \leq 0.05$ level of probability.
[2] Tukey's $_{0.05}$=0.29 (first season) and 0.27 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

2. Pod and seed yield components

As presented in Table 5, the biological yield data show a significant difference among various cvs, potassium sulfate treatments and their interaction. Amendments of potassium sulfate up to 420 kg/ha increased biological yield in all cvs except Nubaria-5. However, this cv remained at the top of the other studied cvs. The relative increase ranged from 9.7% to 43.7% over the two seasons. In contrast, Sakha-1 recorded the highest reduction percentage among faba bean cvs (31.43% and 31.42%) compared to Nubaria-5 at the same potassium sulfate level. Regarding straw yield (ton/ha), the greatest value was noted for the Nubaria-5 cultivar at a potassium sulfate rate of 210 kg/ha (Table 6), but this was not significantly different from the same cv at a potassium sulfate rate of 420 kg/ha. The lowest straw yield was produced by Sakha-1 at different levels of potassium sulfate. Seed yield (ton/ha) was significantly differed among faba bean cvs and potassium sulfate treatments (Table 7). All cvs exhibited an increased seed yield with the elevation of the rate of potassium sulfate up to 420 kg/ha. Nubaria-5 recorded an average increase percentage over the other cvs in the two growing seasons. This increase was estimated by 46% in Sakha-1 cv, 11.5% in Nubaria-4 cv, 42.1% in Giza-716 and 38.2% in Giza-843 when the plants were fertilized with 420 kg/ha potassium sulfate. Sakha-1 cv showed the highest reduction percentage among all faba bean cvs in the two seasons of this study. Consistency, number of pods per plant, pods weight per plant (g), and weight of 100 seeds (g) were increased in all cvs with increasing potassium sulfate up to 420 kg/ha (Tables 8, 9, and 10). In agreement with the other growth and yield data, Nubaria-5 cv recorded the greatest values of average number of pods per plant, pods weight per plant, and weight of 100 seeds compared to the other studied cvs. Meanwhile, Sakha-1 showed the highest reduction among the rest of the faba bean varieties in the two seasons.

Table 5. Influence of faba bean cultivars, potassium sulfate and their interaction on the average of biological yield (ton/ha)

Average biological yield (ton/ha)						
First season 2021/2022						
	Cultivars					
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	9.43^{D}	11.65^{B}	12.67^{A}	10.40^{CD}	10.42^{C}	10.92
210 (kg/ha)	10.03^{D}	13.43^{B}	15.41^{A}	13.53^{B}	11.73^{C}	12.79
420 (kg/ha)	10.60^{C}	14.54^{A}	15.46^{A}	14.73^{A}	12.34^{B}	13.53
Cultivars mean	10.02	13.21	14.51	12.83	11.50	12.41
Tukey $_{0.05}$=0.20[2]						
Second season 2022/2023						
Untreated	9.56^{D}	11.80^{B}	12.87^{A}	10.61^{C}	10.62^{C}	11.09
210 (kg/ha)	10.19^{D}	13.66^{B}	15.66^{A}	13.92^{B}	11.89^{C}	13.06
420 (kg/ha)	10.78^{C}	14.92^{A}	15.72^{A}	15.02^{A}	12.83^{B}	13.85
Cultivars mean	10.18	13.46	14.75	13.18	11.78	12.67
Tukey $_{0.05}$=0.19[2]						

[1] The means within rows followed by different letters are significantly different at $P \leq 0.05$ level of probability.

[2] **Tukey's $_{0.05}$**=0.20 (first season) and 0.19 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 6. Changes of average straw yield (ton/ha) as affected by different cultivars, potassium sulfate, and their interaction

Average straw yield (ton/ha)						
First season 2021/2022						
	Cultivars					
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	5.85^{C}	7.16^{A}	7.70^{A}	6.28^{BC}	6.94^{AB}	6.79
210 (kg/ha)	5.61^{C}	7.98^{B}	9.06^{A}	8.07^{B}	7.42^{B}	7.63
420 (kg/ha)	5.83^{C}	8.62^{A}	8.93^{A}	8.83^{A}	7.19^{B}	7.88
Cultivars mean	5.76	7.92	8.56	7.72	7.18	7.43
Tukey $_{0.05}$=0.17[2]						
Second season 2022/2023						
Untreated	5.87^{C}	7.13^{AB}	7.82^{A}	6.41^{BC}	7.01^{ABC}	6.85
210 (kg/ha)	5.63^{C}	8.00^{AB}	9.12^{A}	8.45^{AB}	7.33^{B}	7.71
420 (kg/ha)	5.89^{C}	8.84^{A}	8.92^{A}	8.95^{A}	7.52^{B}	8.02
Cultivars mean	5.80	7.99	8.62	7.93	7.29	7.53
Tukey $_{0.05}$=0.24[2]						

[1] The means within rows followed by different letters are significantly different at $P \leq 0.05$ level of probability.

[2] **Tukey's $_{0.05}$**=0.17 (first season) and 0.24 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 7. Average dry seed yield (ton/ha) as influenced by faba bean cultivars and various potassium sulfate rates

Average dry seed yield (ton/ha)						
First season 2021/2022						
Cultivars						
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	3.32^{D}	4.50^{B}	4.84^{A}	4.12^{C}	3.34^{D}	4.02
210 (kg/ha)	4.05^{C}	5.44^{B}	6.31^{A}	5.28^{B}	4.32^{D}	5.08
420 (kg/ha)	4.65^{D}	5.92^{B}	6.53^{A}	5.84^{B}	5.08^{C}	5.61
Cultivars mean	4.01	5.29	5.89	5.08	4.25	4.90
Tukey $_{0.05}$=0.05[2]						
Second season 2022/2023						
Untreated	3.43^{C}	4.67^{AB}	4.99^{A}	4.20^{B}	3.44^{C}	4.15
210 (kg/ha)	4.33^{C}	5.67^{B}	6.54^{A}	5.57^{B}	4.56^{C}	5.33
420 (kg/ha)	4.89^{C}	6.08^{B}	6.80^{A}	6.07^{B}	5.30^{C}	5.83
Cultivars mean	4.22	5.47	6.11	5.28	4.43	5.10
Tukey $_{0.05}$=0.108[2]						

[1] The means within rows followed by different letters are significantly different at $P \leq 0.05$ level of probability.
[2] Tukey's $_{0.05}$=0.05 (first season) and 0.108 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 8. Mean of dry pods weight per plant (g) of various faba bean cultivars, potassium sulfate and their interactions

Average dry pods weight per plant (g)						
First season 2021/2022						
Cultivars						
Potassium sulfate[1]	**Sakha-1**	**Nubaria-4**	**Nubaria-5**	**Giza-716**	**Giza-843**	**Mean**
Untreated	63.06^{C}	72.37^{B}	86.39^{A}	66.68^{C}	77.88^{B}	73.28
210 (kg/ha)	69.28^{D}	95.92^{B}	108.66^{A}	96.06^{B}	82.91^{C}	90.57
420 (kg/ha)	75.96^{C}	102.17^{B}	117.21^{A}	100.42^{AB}	95.55^{B}	98.26
Cultivars mean	69.43	90.15	104.09	87.72	85.45	87.37
Tukey $_{0.05}$=4.13[2]						
Second season 2022/2023						
Untreated	64.02^{C}	74.09^{BC}	87.91^{A}	68.68^{C}	79.00^{B}	74.74
210 (kg/ha)	70.97^{D}	98.54^{B}	111.08^{A}	98.68^{B}	84.74^{C}	92.80
420 (kg/ha)	77.05^{C}	103.19^{B}	118.38^{A}	103.42^{B}	99.84^{B}	100.38
Cultivars mean	70.68	91.94	105.79	90.26	87.86	89.31
Tukey $_{0.05}$=2.65[2]						

[1] The means within rows followed by different letters are significantly different at $P \leq 0.05$ level of probability.
[2] Tukey's $_{0.05}$=4.13 (first season) and 2.65 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 9. Influence of faba bean cultivars, potassium sulfate and their interactions on the average number of pods per plant

Average number of dry pods per plant						
First season 2021/2022						
	Cultivars					
Potassium sulfate[1]	Sakha-1	Nubaria-4	Nubaria-5	Giza-716	Giza-843	Mean
Untreated	16.67[C]	20.67[B]	24.67[A]	19.67[B]	25.00[A]	21.33
210 (kg/ha)	17.67[D]	24.67[C]	32.33[A]	23.67[C]	27.67[B]	25.20
420 (kg/ha)	18.00[C]	27.67[B]	43.00[A]	29.33[B]	29.33[B]	29.47
Cultivars mean	17.44	24.33	33.33	24.22	27.33	25.33
Tukey $_{0.05}$=0.41[2]						
Second season 2022/2023						
Untreated	17.00[C]	21.33[B]	25.33[A]	20.00[B]	24.33[A]	21.60
210 (kg/ha)	18.00[D]	25.00[C]	35.00[A]	24.00[C]	28.33[B]	26.07
420 (kg/ha)	18.00[D]	28.33[C]	44.33[A]	30.67[B]	30.00[B]	30.27
Cultivars mean	17.67	24.89	34.89	24.89	27.56	25.97
Tukey $_{0.05}$=0.32[2]						

[1] The means within rows followed by different letters are significantly different at $P\leq0.05$ level of probability.
[2] Tukey's $_{0.05}$=0.41 (first season) and 0.32 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

Table 10. Average weight of 100-seeds (g) as influenced by faba bean cultivars, various potassium sulfate rates and their interaction

Average weight of 100 seeds (g)						
First season 2021/2022						
	Cultivars					
Potassium sulfate[1]	Sakha-1	Nubaria-4	Nubaria-5	Giza-716	Giza-843	Mean
Untreated	81.17[B]	82.67[B]	89.67[A]	83.83[AB]	82.53[B]	83.97
210 (kg/ha)	86.00[B]	94.33[A]	94.00[A]	91.33[AB]	88.00[AB]	90.73
420 (kg/ha)	95.00[B]	95.50[B]	97.67[A]	96.17[B]	93.17[C]	95.50
Cultivars mean	87.39	90.83	93.78	90.44	87.90[b]	90.07
Tukey $_{0.05}$=1.29[2]						
Second season 2022/2023						
Untreated	84.81[C]	86.55[B]	91.91[A]	83.43[C]	85.71[B]	86.48
210 (kg/ha)	91.26[C]	95.62[B]	96.61[A]	95.68[B]	89.55[C]	93.74
420 (kg/ha)	94.99[C]	96.49[B]	99.31[A]	97.67[B]	95.77[C]	96.85
Cultivars mean	90.35	92.89	95.94	92.26	90.34	92.36
Tukey $_{0.05}$=1.07[2]						

[1] The means within rows followed by different letters are significantly different at $P\leq0.05$ level of probability.
[2] Tukey's 0.05=1.29 (first season) and 1.07 (second season) are to separate means within columns (treatments of potassium sulfate under the same cv).

3. Cluster analysis

The similarity coefficient among faba bean cultivars in response to different potassium sulfate rates ranged from 0.900 to 0.990, with an average value of 0.945 (Fig. 2). All faba bean cultivars were separated into two main clusters or groups at a similarity of 0.930. Out of five cvs, the Nubaria-5 cv appeared in a separate group (cluster I). However, the rest of the faba bean cvs appeared in another group (cluster II). More specifically, at a similarity of 0.975, cluster II was divided into two subgroups (subgroups A and B). Three of the four faba bean cvs in cluster II appeared in sub-group A, which are Nubaria-4, Giza-716, and Giza-843. Meanwhile, only one cv (Sakha-1) was presented in sub-group B.

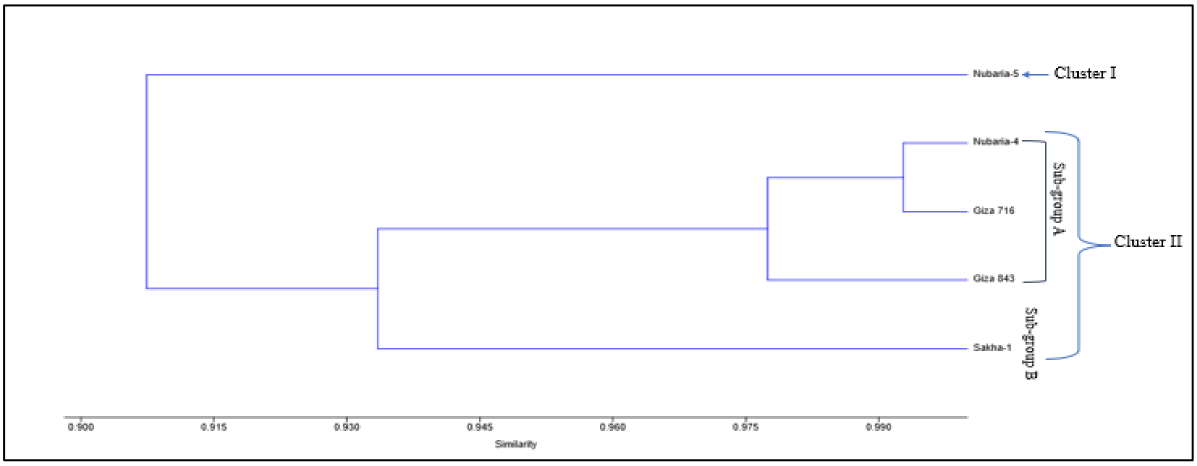

Fig. 2. Cluster dendrogram of five faba bean varieties based on the average of two seasons (2021/2022 and 2022/2023) of phenotype and yield component traits.

4. Irrigation water productivity (kg/m^3)

The illustrated results in Fig. (3) showed that the lowest values of IWP were 0.61 and 0.62 kg/m^3 for Giza-843 cv under untreated treatment during the two seasons, while the highest values were 1.15 and 1.17 kg/m^3 for Nubaria-5 cv under application of 420 kg/ha potassium sulfate. The results exhibited that the application of potassium sulfate enhanced irrigation water productivity for new faba bean cultivars.

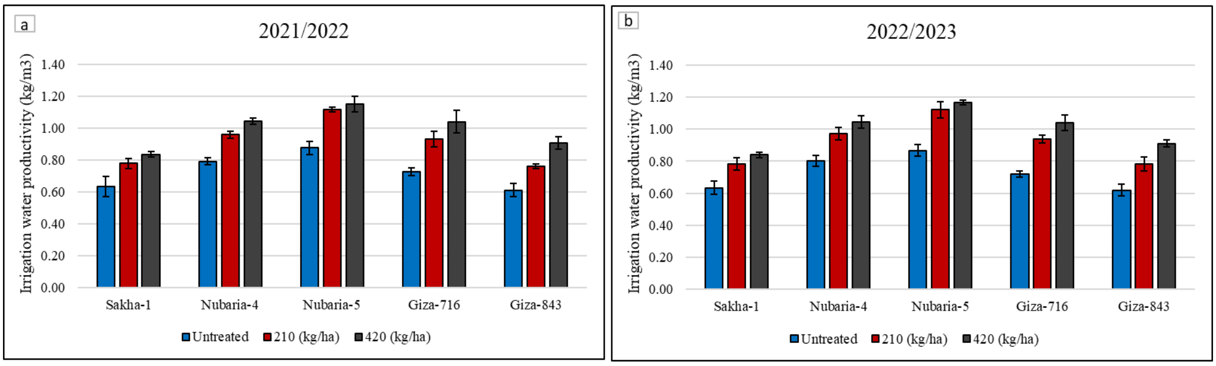

Fig. 3. Influences of potassium sulfate on irrigation water productivity of five newly faba bean cultivars.

5. Nutrient elements content of the Shoot tissues

The shoot tissue contents of nitrogen, phosphorus, potassium, and sulfur as affected by cultivars and potassium sulfate amendments are revealed in Tables 11, 12, 13, and 14. No interactions between these factors were detected for nitrogen, potassium, and sulfur. However, the nitrogen, phosphorus, potassium, and sulfur percentages in shoot tissues increased when potassium sulfate was applied compared to the untreated control, this increase was observed at both rates of potassium sulfate. The increase percentages at the highest potassium sulfate rate were 32.24%, 90.23%, 55.73%, and 55.53% as an average of two seasons, for nitrogen, phosphorus, potassium, and sulfur respectively. Cultivar Nubaria-5 had higher percentage of phosphorus content compared to cv Sakha-1 when they received the first or the second rate of potassium sulfate. This cultivar exhibited higher percentage of potassium than cv Sakha-1 only when the plants were fertilized with the higher rate of potassium sulfate. No difference between the two cvs was detected in nitrogen content while the difference was inconsistent for sulfur.

Table 11. Nitrogen percentage in plant shoot tissues in two faba bean cultivars treated with different rates of potassium sulfate

Nitrogen percentage in shoot				
First season 2021/2022				
Cultivars				
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean**	**Difference between the two cvs[2]**
Untreated	1.69	1.75	1.73	ns
210 (kg/ha)	2.07	2.11	2.09	ns
420 (kg/ha)	2.28	2.34	2.31	ns
Cultivars mean	2.01	2.07	2.04	
Tukey's $_{0.05}$=0.05[1]				
Second season 2022/2023				
Untreated	1.74	1.88	1.81	ns
210 (kg/ha)	2.20	2.25	2.23	ns
420 (kg/ha)	2.35	2.40	2.37	ns
Cultivars mean (ns)	2.10	2.17	2.14	
Tukey's $_{0.05}$=0.04[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns: insignificant at 0.05 level of probability.

Table 12. The contents of phosphorus in shoot tissues in Sakha-1 and Nubaria-5 cultivars fertilized with different rates of potassium sulfate

Phosphorus percentage in shoot				
First season 2021/2022				
Cultivars				
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean (**)**	**Difference between the two cvs[2]**
Untreated	0.24	0.27	0.25	ns
210 (kg/ha)	0.35	0.42	0.38	*
420 (kg/ha)	0.46	0.51	0.48	*
Cultivars mean Tukey's $_{0.05}$=0.01[1]	0.35	0.40	0.37	
Second season 2022/2023				
Untreated	0.24	0.29	0.26	ns
210 (kg/ha)	0.35	0.46	0.41	*
420 (kg/ha)	0.46	0.51	0.49	*
Cultivars mean (**)	0.35	0.42	0.39	
Tukey's $_{0.05}$=0.005[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and * and ** are insignificant and significate, respectively, at 0.05 or 0.01 level of probability.

Table 13. Potassium level in shoot tissues of faba bean cultivars subjected to three levels of potassium sulfate

Potassium in shoot (%)				
First season 2021/2022				
	Cultivars			
Potassium sulfate	Sakha-1	Nubaria-5	Mean	Difference between the two cvs[2]
Untreated	1.11	1.14	1.12	ns
210 (kg/ha)	1.54	1.58	1.56	ns
420 (kg/ha)	1.75	1.82	1.79	*
Cultivars mean (ns)	1.46	1.52	1.49	
Tukey's $_{0.05}$=0.07[1]				
Second season 2022/2023				
Untreated	1.22	1.22	1.22	ns
210 (kg/ha)	1.57	1.61	1.59	ns
420 (kg/ha)	1.81	1.90	1.85	*
Cultivars mean (ns)	1.53	1.58	1.56	
Tukey's $_{0.05}$=0.02[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and * are insignificant and significate, respectively, at 0.05 level of probability

Table 14. Mean of sulfur concentration in shoot tissues of Sakha-1 and Nubaria-5 cultivars as influenced by application of several potassium sulfate rates

Sulfur in shoot (%)				
First season 2021/2022				
	Cultivars			
Potassium sulfate	Sakha-1	Nubaria-5	Mean	Difference between the two cvs[2]
Untreated	0.21	0.23	0.22	ns
210 (kg/ha)	0.28	0.30	0.29	ns
420 (kg/ha)	0.33	0.35	0.34	ns
Cultivars mean Tukey's $_{0.05}$=0.018[1]	0.27	0.29	0.28	
Second season 2022/2023				
Untreated	0.22^{d}	0.23^{d}	0.23^{c}	ns
210 (kg/ha)	0.31^{c}	0.32^{bc}	0.31^{b}	ns
420 (kg/ha)	0.35^{ab}	0.38^{a}	0.36^{a}	*
Cultivars mean	0.30^{a}	0.31^{a}	0.30	
Tukey's $_{0.05}$=0.005[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and * are insignificant and significate, respectively, at 0.05 level of probability

6. Seed contents of nutrient elements and protein

The statistical analysis presented in Tables 15, 16, 17, 18, and 19 shows no initial differences for phosphorus, potassium and sulfur between untreated cvs. However, significant initial differences were found between the two cvs in nitrogen and protein percentages. Seeds of cv Nubaria-5 contained, on average, 5.7% and 4.9% higher nitrogen and protein, respectively, than cv Sakha-Compared with seeds of the untreated plants, adding 210 kg/ha potassium sulfate increased all the studied elements. Further increase occurred when fertilized with a higher rate of potassium sulfate (420 kg/ha). The seed content of protein and the elements, except phosphorus, were higher in cultivar Nubaria-5 than in Sakha-1 cv.

Table 15. Influence of faba bean cultivars, potassium sulfate and their interactions on nitrogen percentage in seed

Nitrogen in seed (%)				
First year 2021/2022				
Cultivars				
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean (**)**	**Difference between the two cvs[2]**
Untreated	2.33	2.44	2.38	*
210 (kg/ha)	2.64	2.83	2.73	*
420 (kg/ha)	2.86	3.01	2.93	*
Cultivars mean Tukey's $_{0.05}$=0.005[1]	2.61	2.76	2.68	
Second season 2022/2023				
Untreated	2.34	2.49	2.41	*
210 (kg/ha)	2.67	2.86	2.77	*
420 (kg/ha)	2.87	3.04	2.95	*
Cultivars mean (*) Tukey's $_{0.05}$=0.04[1]	2.63	2.80	2.71	

[1] To separate two potassium sulfate means under the same cultivar.
[2] * and ** are significate respectively at 0.05 or 0.01 level of probability

Table 16. Phosphorus contents in seed of two faba bean cultivars treated with different rates of potassium sulfate

Phosphorus in seed (%)				
First season 2021/2022				
Cultivars				
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean (**)**	**Difference between the two cvs[2]**
Untreated	0.14	0.17	0.15	ns
210 (kg/ha)	0.23	0.24	0.23	ns
420 (kg/ha)	0.28	0.27	0.27	ns
Cultivars mean	0.22	0.23	0.22	
Tukey's $_{0.05}$=0.005[1]				
Second season 2022/2023				
Untreated	0.14	0.17	0.15	ns
210 (kg/ha)	0.23	0.24	0.24	ns
420 (kg/ha)	0.28	0.27	0.27	ns
Cultivars mean	0.22	0.23	0.22	
Tukey's $_{0.05}$=0.005[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and ** are insignificant and significate, respectively, at 0.01 level of probability

Table 17. Mean of potassium concentration in seed of Sakha-1 and Nubaria-5 cultivars as influenced by application of several potassium sulfate rates

Potassium in seed (%)				
First season 2021/2022				
	Cultivars			
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean**	**Difference between the two cvs[2]**
Untreated	0.94	0.94	0.94	ns
210 (kg/ha)	1.05	1.25	1.15	*
420 (kg/ha)	1.18	1.35	1.26	*
Cultivars mean	1.06	1.18	1.12	
Tukey's $_{0.05}$=0.03[1]				
Second season 2022/2023				
Untreated	0.96	0.99	0.97	ns
210 (kg/ha)	1.11	1.28	1.19	*
420 (kg/ha)	1.19	1.36	1.27	*
Cultivars mean	1.08	1.21	1.15	
Tukey's $_{0.05}$=0.01[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and * are insignificant and significate, respectively, at 0.05 level of probability.

Table 18. Sulfur level in seed of faba bean cultivars subjected to three levels of potassium sulfate

Sulfur in seed (%)				
First season 2021/2022				
	Cultivars			
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean (**)**	**Difference between the two cvs[2]**
Untreated	0.10	0.12	0.11	ns
210 (kg/ha)	0.14	0.16	0.15	*
420 (kg/ha)	0.16	0.19	0.17	*
Cultivars mean (**)	0.13	0.16	0.14	
Tukey's $_{0.05}$=0.005[1]				
Second season 2022/2023				
Untreated	0.10	0.12	0.11	ns
210 (kg/ha)	0.15	0.18	0.16	*
420 (kg/ha)	0.17	0.21	0.19	*
Cultivars mean (*)	0.14	0.17	0.15	
Tukey's $_{0.05}$=0.005[1]				

[1] To separate two potassium sulfate means under the same cultivar.
[2] ns and * and ** are insignificant and significate, respectively, at 0.05 or 0.01 level of probability.

Table 19. Effect of faba bean cultivars, potassium sulfate, and their interaction on seed protein percentage

Protein in seed (%)				
First season 2021/2022				
	Cultivars			
Potassium sulfate	**Sakha-1**	**Nubaria-5**	**Mean**	**Difference between the two cv[2]**
Untreated	14.54	15.25	14.90	*
210 (kg/ha)	16.48	17.68	17.08	*
420 (kg/ha)	17.86	18.79	18.32	*
Cultivars mean Tukey's $_{0.05}$=0.07[1]	16.29	17.24	16.77	
Second season 2022/2023				
Untreated	14.63	15.57	15.10	*
210 (kg/ha)	16.71	17.89	17.30	*
420 (kg/ha)	17.92	18.97	18.44	*
Cultivars mean Tukey's $_{0.05}$=0.25[1]	16.42	17.48	16.95	

[1] To separate two potassium sulfate means under the same cultivar.
[2] * is significate at 0.05 level of probability

Discussion

The current investigation compared the performance of developed faba bean cultivars grown in calcareous sand soils and highlighted the significant impact of potassium sulfate fertilization in the form of potassium sulfate. The obtained results showed that the studied cultivars have different responses to potassium sulfate rates under calcareous soil conditions. In response to K treatments, the agronomic traits, i.e., plant height, number of branches per plant, biological yield, straw yield, number of pods per plant, average pods weight, seed yield, and 100-seed weight, increased compared to control plants. Barłóg and Łukowiak (2021) mentioned that a sufficient K supply could provide ATP and the electrons required for nitrogenase reduction by translocating higher amounts of photosynthates from plant leaves to plant roots and root nodules. The potassium effect mechanism can occur in two ways: directly through increased nitrogenase activity and indirectly through plant dry matter and nodule number stimulation.

Moreover, the improvement due to the application of K_2SO_4 could be attributed to the presence of sulfur and the importance of this element to legume crops grown on calcareous soils (Bezabeh *et al*. 2021), especially with the introduction of high-yielding cvs. Kaya *et al*. (2020) reported that sulfur is an essential element required for maintaining optimal plant growth. The positive impact of S on plant growth and crop yield has been observed in several crops, i.e., potato (Sanli *et al.* 2013), canola (Govahi and Saffari 2006), and maize (Kaya *et al.* 2020). The positive effect of sulfur could be through several functions, i.e., enhancing the number and growth of nodules (Scherer 2008 and Varin *et al*., 2010); stimulating the biosynthesis and activity of nitrogenase, which is the most important enzyme responsible for fixing N_2 (Kaiser *et al.* 2005 and Pacyna *et al.* 2006); increasing the availability of some nutrients from the soil reserves, including potassium element, due to its strong acidification (Zhou *et al*. 2009); converting large volumes of $CaCO_3$ to $CaSO_4$; and stimulating S-oxidizing microorganism developments and modifying the interactions in the soil among various microorganism groups (Niewiadomska *et al*. 2015). Pacyna *et al*. (2006) reported that under S-deficient conditions, low activity of the nitrogenase enzyme was recorded due to low energy supply to the nodule. Due to the fact that the experimental land is sandy soil, the plant properties will be negatively affected by drought due to the sand soil draining large amounts of water (Hag and Dalia 2017). As sulfur participates in sulfur-containing compounds, it plays a critical role in osmotic adjustment in plants exposed to water stress (Abuelsoud *et al.* 2016 and Kaya *et al*. 2020). Abdelhamid *et al.* (2013) observed that the application of sulfur improved soil water content.

Potassium sulfate has been shown to significantly enhance the water productivity of faba bean (*Vicia faba*) plants. This effect is attributed to several physiological and biochemical mechanisms that improve plant resilience and growth. Research indicates that potassium sulfate applications can improve water use efficiency in faba beans. Potassium plays a critical role in regulating stomatal conductance, which helps maintain leaf hydration and reduces water loss through transpiration. Studies have demonstrated that potassium sulfate applications lead to increased relative water content in leaves, which is crucial for sustaining plant growth (Siam *et al.* 2017; Barlog *et al.* 2019; Abd Allah *et al.* 2021; Abdelaal 2023; Ersoy *et al.* 2024).

Nutrient contents in plant shoots or seeds are positively affected by potassium sulfate application. As the K rate increased, the N percentage increased as a result of the positive role of potassium in stimulating N transportation from the nodules of roots to the above-ground plant parts (Pettigrew, 2008). Moreover, Cazzato *et al.* (2012) mentioned that sulfur treatments increased nitrogen accumulation and legume yield on S-deficient soil. Under calcareous soil conditions, the most limiting element for crop production is P. The obtained results showed an increase in P levels with potassium sulfate application. This could be due to the presence of S, which increases the availability of P in calcareous soils as a result of reducing soil pH and increasing P solubility (Erdal *et al*. 2006 and Khan *et al*. 2017). Legume crops, as nitrogen-fixing plants, require P for adequate growth and nodulation (Tan *et al.,* 2001). In wheat grain, with increasing sulfur application, a significant increase in phosphorus, potassium, and sulfur concentrations was observed (Abdallah *et al*. 2013). The results of the current investigation support this phenomenon. Sulfur is considered an important component of proteins and has an important role in the metabolic and physiological changes in legume crops (Niewiadomska *et al.* 2015). Ghafoor *et al.* (2021) reported that S is very important for nitrogen use efficiency, especially in the formation of protein contents. Taking into account the positive effect of potassium and sulfur-rich soil on the nutrient content of plant shoots and seeds, a significant increase in seed yield was observed.

These improvements were significantly varied among the faba bean cultivars; a lower pod number and pod weight per plant resulted in a lower grain yield. Amarowicz and Pegg (2008) reported that the impact of sulfur application may depend on the genotype. There is a difference among faba bean genotypes in the absorption of photosynthetically active radiation due to the variance of leaf area, and with sufficient K supply, this will contribute to a higher grain yield. Pettersson *et al.* (1983) reported that various genotypes express different high-affinity potassium transporters with diverse potassium uptake efficiencies. Identifying high-nutrient-use-efficiency cultivars in poor-fertility calcareous soil is crucial for the expansion of newly reclaimed land and has positive environmental impacts through a decrease in chemical usage in agriculture. Therefore, in the current investigation, a cluster tree was constructed based on the morphological and yield component traits of faba bean cultivars to clarify the genetic diversity status in response to potassium sulfate treatments. A study by White *et al.* (2010) demonstrated an approximately 3-4- fold difference among *Brassica oleracca* genotypes in the shoot potassium concentration. Also, a significant genetic variation was observed among Arabidopsis germplasm in the K content of plant shoots (Harada and Leigh, 2006). The variation in K^+ acquisition among different genotypes might be attributed to: the uptake rate of K^+ through the plasma membrane of root cells, in terms of decreasing the concentration of K^+ in the rhizosphere solution and increasing diffusional K^+ fluxes; roots proliferation into the soil volume, in terms of extending the area for K^+ uptake and decreasing the required distance for K^+ diffusion and water flow; non-exchangeable K+ release by root exudates, which enhances the concentration and availability of K^+ in the soil solution; and plant transpiration rate, which drives mass flow of the soil solution to the plant roots (White *et al.*, 2010). Zhao *et al.* (2011) confirmed the differences among genotypes in K-efficiency, where they identified one tomato cultivar as K^+-efficient and another one considered a K^+-inefficient genotype. Genotype variation in K uptake and utilization has been observed in economically important crops, i.e., wheat genotypes (Osman *et al.,* 2021), maize (Farina *et al.* 1983), rice (Yang *et al.* 2004), soybean (Sale and Campbell 1987), potato (Trehan *et al*. 2005), and sweet potato (George *et al*. 2002). Plant breeders, in the development of breeding populations, can use information on genetic similarity to complement phenotypic information (Mostafa *et al.* 2020). The rich information obtained might be helpful for breeding new cultivars of the faba bean crop in the future.

Conclusions

The null hypothesis is rejected as a potential variation was detected among the studied factors. Combinations between K and S have the potential to improve and enhance faba bean growth, productivity, and seed nutrient content. The cv Nubaria-5 laid on top of the assessed cvs. and can be recommended for production in reclaimed calcareous soil supplemented with 420 kg/ha potassium sulfate in the tested region. This cv seemed to efficiently uptake sulfur and the main nutrient elements.

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دراسة مقارنة للفول البلدي لتوضيح الدور المهم لكبريتات البوتاسيوم والاصناف في الاراضي الرملية الجيرية

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الملخص

يُعدّ دعم الاراضي الرملية الجيرية بمُحسِّنات التربة أمرًا بالغ الأهمية لتعزيز نمو النباتات وزيادة إنتاجية المحاصيل. وقد وُثِّقت فعالية استخدام كبريتات البوتاسيوم في هذا الصدد، إلا أن المعلومات المتاحة حول إمكانية استجابة الأصناف قليلة. لذلك، صُمِّم البحث الحالي لاختبار تأثير معدلات مختلفة من استخدام كبريتات البوتاسيوم (الكنترول، 420،210 كجم/هكتار) على خصائص النمو والإنتاجية لخمسة أصناف جديدة من الفول البلدي (سخا-1، نوبارية-4، نوبارية-5، جيزة 716، وجيزه 843) تحت ظروف الاراضي الرملية الجيرية. أظهرت النتائج أن صنف الفول البلدي "نوبارية-5" سجّل أعلى قيمة لنمو النبات، والمحصول، ومكوناته، ونسب النيتروجين، والفوسفور، والبوتاسيوم، والكبريت في الأفرع والبذور خلال موسمي الزراعة 2022/2021، 2023/2022. وأظهر تحليل المجموعات العنقودية ظهور الصنف "نوبارية-5" في مجموعة منفصلة، مما يؤكد اختلافه عن بقية الأصناف المستخدمة. وفي الختام، يُلاحظ وجود تباين صنفي، ويمكن استخدامه بالتزامن مع إضافات الكبريت في الخطة الاستراتيجية لتحسين إنتاجية محصول الفول البلدي في الاراضي الرملية الجيرية.

الكلمات المفتاحية: أصناف جديدة، الاراضي الرملية الجيرية، الكبريت، الاراضي المستصلحة، نقص الكبريت.