Egyptian Journal of Soil Science
http://ejss.journals.ekb.eg/

Maximizing Faba Bean Tolerance to Soil Salinity Stress Using Gypsum, Compost and Selenium

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SALINE soils are difficult to manage. Still, with the use of suitable fertilization programs, the productivity of these soils may be improved considerably. Accordingly, a field trial was implemented to evaluate the effectiveness of alleviating the oxidative stresses on faba bean plants grown under soil salinity stress via gypsum, compost and selenium (Se).Four soil amendment treatments [$\mathbf{T_0}$**:** Control; $\mathbf{T_1}$**:** Gypsum; $\mathbf{T_2}$**:** Compost**;** $\mathbf{T_3}$**:** Gypsum +compost] andfive foliar Seapplication rates (0, 2.5, 5.0 7.5 and 10.0 mg L^{-1}) were studied.All studied treatments significantly affected all studied parameters. The maximum contents of malondialdehyde (MDA) and proline were recorded under$\mathbf{T_0}$treatment, while the lowest values were realized under $\mathbf{T_3}$treatment.The maximum values were achieved with plants sprayed with 10.0 Se mg L^{-1}.While the lowest values were realized with plants sprayed with 5.0 Se mg L^{-1}.The $\mathbf{T_3}$ treatment was the most effective for the growth performance traits and productivity. The Setreatments had a significant and gradual effect on the growth performance traits and productivity, with an increase observed as the Se rate was increased from 0.0 mgL^{-1} to 5.0 mgL^{-1}, followed by a significant and gradual decrease until the Se concentration reached 10.0 mgL^{-1}.Generally, by using suitable soil amendments and Se foliar application, the productivity of faba bean plants can be improved even under soil salinity stress. Overall, these findings provide a potential solution for improving faba bean production in challenging environments and could help pave the way for further research in this area.

Keywords: MDA, proline, oxidative-stress induced.

1. Introduction

Egypt heavily depends on agriculture and agricultural reclamation to meet its food needs and achieve food self-sufficiency. Unfortunately, the degradation of the country's agricultural soils has made it challenging to fulfil these requirements **(El-Ramady *et al.* 2019; Ghazi *et al.* 2022a).**Saline soils in Egypt are among the main challenges that affect negatively the productivity of plants grown on such soils**(Ghazi*et al.* 2022b).**This is because, the high levels of salt in soil can create an osmotic imbalance, drawing water out of the plant's roots and causing water stress **(Yildiz*et al.*2020).**This can reduce the plant's ability to absorb essential nutrients, leading to stunted growth, yellowing leaves, and even plant death**(Liang *et al.* 2018).** Moreover, excessive levels of specific ions in soil*i.e.*, sodium can cause toxicity in plantsand also deterioration in soil structure and these conditions makes plants difficult to penetrate the soil while reduce nutrient uptake and plant growth **(Nada *et al.* 2023).**There are several methods that can be used to combat the damage caused by saline soils to the growing crop such as adding amendments (gypsum and organic matter) to the soil which may help to reduce soil salinity levels and improve soil structure, water retention, and nutrient availability **(Amer and Hashem 2018; Ghazi *et al.* 2021).**

Agricultural gypsum is an effective tool for reclamation of sodic soil via increasing the solubility of soil Ca to replace Na on soil particles and improve soil structure, and enhance nutrient availability ; thus, gypsum can create a healthier soil environment for plant growth and improve agricultural productivity in areas affected by soil salinity **(Abo El-Ezz*et al.*2020).** Agricultural gypsum plays a crucial role in

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Received: 29/03/2023; Accepted: 27/04/2023
DOI: 10.21608/ejss.2023.203083.1582

soil management due to its ability to reduce sodium (Na^+) accumulation in the soil matrix, which is a significant problem for plant growth and yield when present at high levels (**Ghazi *et al.* 2021).** Gypsum replaces the harmful sodium ions with calcium ions, leading to improved soil structure and water-holding capacity. Furthermore, gypsum can lower the soil's pH, making it more acidic, which can increase the availability of essential nutrients for plants **(**Sheikh ***et al.* 2022).**

Organic amendments, like compost, have a considerable impact on soil quality. They are beneficial because they can improve soil biological characteristics by providing a food source and habitat for helpful microorganisms like bacteria, fungi, and earthworms that are vital for nutrient cycling and soil health **(Aytenew and Bore 2020).** Organic amendments also help to enhance soil structure and water-holding capacity while increasing soil organic matter content, which enhances nutrient availability and water retention. Moreover, organic amendments release plant-available nutrients like nitrogen, phosphorus, and potassium slowly over time as the organic matter decomposes, providing a steady source of nutrition for plants. Organic amendments can also help to reduce soil compaction, which can improve root growth and water infiltration**(Guo*et al*. 2020).**Organic fertilizers such as compost can play an important role in the reclamation of salt-affected soils, as these additives combine soil particles together and improve soil structure and fertility, which may lead to better plant growth and productivity under salinity conditions **(Elshony *et al*. 2019; Farid *et al*. 2021 a &b)**. For example, compost can be an effective tool for the reclamation of salt-affected soils by improving soil structure, increasing nutrient availability, promoting microbial activity, and reducing soil salinity(**Hussein *et al.* 2022).** Generally, organic fertilizers can help to create a healthier soil environment for plant growth and improve agricultural productivity under salinity conditions **(Elsherpiny *et al.* 2023)**.

Spraying antioxidants on crops can also help to combat the damage caused by saline soils on the grown plants. These antioxidants reduce the impacts of salt stress on crop growth; hence protect plants from damage caused by synthesis of free radicals and other reactive oxygen species, which are produced in excess within the tissues of salt-stressed plants. However, it is important to choose the right type of antioxidant and apply it at the right time **(Ghazi *et al.* 2023).** Selenium is a trace element that can act as an antioxidant in plants **(Xiang *et al.* 2022).** It is beneficial nutrient for many plants. Selenium may be absorbed by plants in different forms, including selenite ($SeO4^{2-}$) or selenite ($SeO3^{2-}$) as well as in organic form, such as Se-amino acid, specifically as Se-methionine (Se-met) **(White 2018).** Selenium can protect plants from oxidative stress by scavenging free radicals and reducing reactive oxygen species (ROS) in cells **(Mansoor*et al.* 2022).** Selenium can act as an effective antioxidant on plants by protecting cells, enhancing defense mechanisms, and increasing tolerance to stress**(Das *et al.* 2022).** However, it is important to note that excessive selenium can be toxic to plants, so proper dosing and monitoring are essential for safe and effective use **(Mahmoud *et al.* 2023).**

Faba bean (*Vicia faba* L.) is a highly valued strategic crop in Egypt, providing food security, income generation, crop rotation benefits, and climate change resilience. Faba bean is an important source of protein and essential nutrients, and is a staple food for millions of Egyptians. Its continued cultivation and improvement are critical for the sustainable development of Egyptian agriculture and food systems **(Abdeen and Hefni 2023).** Faba bean exhibits sensitivity to salinity stress, which adversely impacts its growth, yield, and quality. Salt stress affects the germination and seedling phases of the plant, which can hamper the establishment and result in a decreased yield. Additionally, salinity stress affects seed quality, decreasing protein and starch levels while increasing salt concentration. However, the implementation of appropriate management practices can mitigate the harmful effects of salinity stress on faba bean **(Baddour *et al.* 2021)**.

The objective of this study was as follows;

1. To determine the effect of soil salinity stress on the growth and development of faba bean plants.
2. To investigate the effect of soil amendments (gypsum and compost) on the reduction of soil salinity stress on faba bean plants.
3. To assess the potential of foliar application of selenium in alleviating oxidative stress induced by soil salinity stress in faba bean plants.

4. To determine the optimal rate of selenium application for maximum alleviation of oxidative stress in faba bean plants under soil salinity stress.
5. To evaluate the interactions between soil amendments (gypsum and compost) and foliar selenium application in alleviating the negative effects of soil salinity stress on faba bean plants.

2. Material and Methods

- Experimental site and treatments

A field research experiment was carried out throughout two consecutive seasons, specifically in 2021/22 and 2022/23, at a geographical location with a latitude of 31°31'47.64" N and a longitude of 30°56'12.88" E[Tag El-Ezz Experimental Farm, Agricultural Research Station (ARS), Egypt].

The current trial was implemented under a split plot design with three replicates. Four soil amendment treatments [**T_0:** Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them] represented the main plots. While different selenium rates [**Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1})] were allocated in the sub plots. The sub-sub plot size was 10.5 m^2 (3.0 m × 3.5 m).

- Applied treatments and their sources

Compost and agricultural gypsum were purchased from the Egyptian commercial market. While selenium as sodium selenite (Na_2SeO_4, from Sigma Company) was obtained from the Faculty of Agriculture, Mansoura University, Egypt. The standard procedures outlined by **Tandon (2005)** were used in analyzing both compost and agricultural gypsum. Table 1 shows the properties of the compost and agricultural gypsum prior to the experimental study. The levels of sulfur and calcium in gypsum were determined using the reagents such as used barium chloride solution ($BaCl_2$) and HCl, as the wavelength used in this method was 420 nm **(Rice *et al.* 2012).**

Table 1. Properties of the initial soil, compost, and agricultural gypsum.

Property	Initial soil	Compost	Agricultural gypsum ($CaSO_4$. $2H_2O$)
pH	8.2 (suspension 1:2.5)	6.16 (suspension 1:10)	7.8 (suspension 1: 5)
EC, dSm^{-1}	6.26	3.54	2.5
Total C, %	/	18.41	/
Total N, %	/	1.56	/
C:N ratio	/	11.80	/
Purity, %	/	/	98.3
Calcium content, g $100g^{-1}$	/	/	22.9
Sulfur content , g $100g^{-1}$	/	/	17.9
Available N, $mgKg^{-1}$	44.2	/	/
Available P, mg kg^{-1}	8.92	0.62	/
Available K, mg kg^{-1}	210.	6.00	/
Mn, mg kg^{-1}	/	28.0	/
Zn, mg kg^{-1}	/	23.0	16.0
Organic matter,%	1.56	15.3	/
Sand	21.00	/	/
Clay	50.00	/	/
Silt	29.00	/	/
Textural	Clayey	/	/

Note: The data presented in this table is the combined data over both studied seasons.

To prepare the soil for sowing, a series of measures were taken over a two-month period. Regarding the studied gypsum treatments, in the two months leading up to sowing, the soil was subjected to regular irrigation after the addition of agricultural gypsum until it reached its saturation limit, where the added water was approximately 10 cm higher. This process was carried out every 15 days to remove excess sodium from the soil. In relation to the compost treatments that were investigated, the plots were given the compost two weeks prior to the cultivation. The studied soil amendments were thoroughly mixed with the surface of the studied soil layer according to the studied treaments.

A standard solution was created using a specific concentration by dissolving a precise amount of sodium selenite in the solvent. This standard solution was then used to prepare various concentrations for the study. The foliar application of Se was carried out 30 days after sowing and then repeated three times at 14-day intervals by hand sprayer (with volume of 850 L ha^{-1}).

- **Cultivation**

Faba bean plant was chosen as a model crop, as the seeds (Giza 716, early cultivar) were brought from Food Legumes Dep., Field Crop Res., Inst., Agriculture Research Center (ARC), Giza, Egypt. The recommended seed rate (almost 95 kg ha^{-1}) was sown on 28th October in both seasons under a flooding irrigation system. The seeds were coated with Rhizobium inoculum (a rate of 10 g per 1.0 kg of seeds) before sowing using 40% Arabic gum as a sticky material. Then they were sown directly by hand in hills (3 seeds per hill) on the shoulder bed and in the top 1/3 of the row ridge. After 20 days from sowing, they were thinned out to two plants per hill. Prior to sowing, all plots were treated with calcium superphosphate (15% P_2O_5) at a rate of 100 kg fed^{-1} and potassium sulfate (48% K_2O) at a rate of 50 kg K_2O fed^{-1}. The effective nitrogen dose, in the form of ammonium sulfate (20.5% N), was applied in a single dose 15 days after sowing and before the first irrigation. To control broomrapes (*Orobanche* spp.), a vital product was utilized. Other recommended agricultural practices for faba beans were implemented in accordance with the guidelines set by the Egyptian Ministry of Agriculture.

- **Soil and plant sampling**

Soil samples were collected prior to the experimental study, at a depth of 0-30 cm. These samples were air-dried, sieved to pass through a 2 mm sieve and analyzed for their characteristics. Table 1 shows the properties of the soil prior to the experimental study. Particle size distribution (%) was characterized using the pipette method as described by **Gee and Bauder (1986),** whilst textural class was identified using the soil texture triangle according to ISSS. All soil chemical characteristics was determined according to the standard procedures outlined by **Sparks *et al.* (2020).** At a period of 70 and 100 days after sowing, a selection of five plants were randomly sampled from each replicate in order to estimate the characteristics presented in Fig 1.

- **Statistical analysis**

The data was analyzed using the statistical technique described by **Gomez and Gomez (1984)** and **CoStat version 6.303 copyright (1998-2004).** Treatment means were compared using the least significant difference (LSD) at a significance level of 0.05.

3. Results

- **Malondialdehyde (MDA) and proline (as non-antioxidant)**

Table 2 shows the individual effect of gypsum, compost and selenium as well as their combinations on the values of both malondialdehyde (MDA) and proline in leaves of faba bean plant during seasons of 2021/22 and 2022/23 at the period of 70 days from sowing. The maximum (9.51 and 9.61 for MDA and 6.64 and 6.71 for proline in both studied seasons, respectively) were achieved under control treatment While decreased significantly with the application of soil additives. In this concern, the lowest values (4.99 and 5.05 for MDA and 3.84 and 3.89 for proline in the 1st and 2nd seasons, respectively) were obtained under the combined treatment (gypsum+ compost)*i.e.* T_3. Concerning the selenium treatments, it was noticed that the maximum values of both MDA and proline (7.61 and 7.7 for MDA and 5.71 and 5.79 for proline in both studied seasons, respectively) were achieved with plants sprayed with 10.0 Se mg L^{-1}followed by the control treatment (grown without Se), while the lowest values (6.35 and6.44 for MDA and 4.95 and 5.01 for proline in both seasons, respectively)were realized with plants sprayed with Se at concentration of 5.0 mg L^{-1}. In this regard, it can be noticed that the combined treatment (**T_0× Se_4**)recorded the highest values of both MDA and proline, whilst the combined treatment (**T_3× Se_2**) caused the lowest values of both MDA and proline.

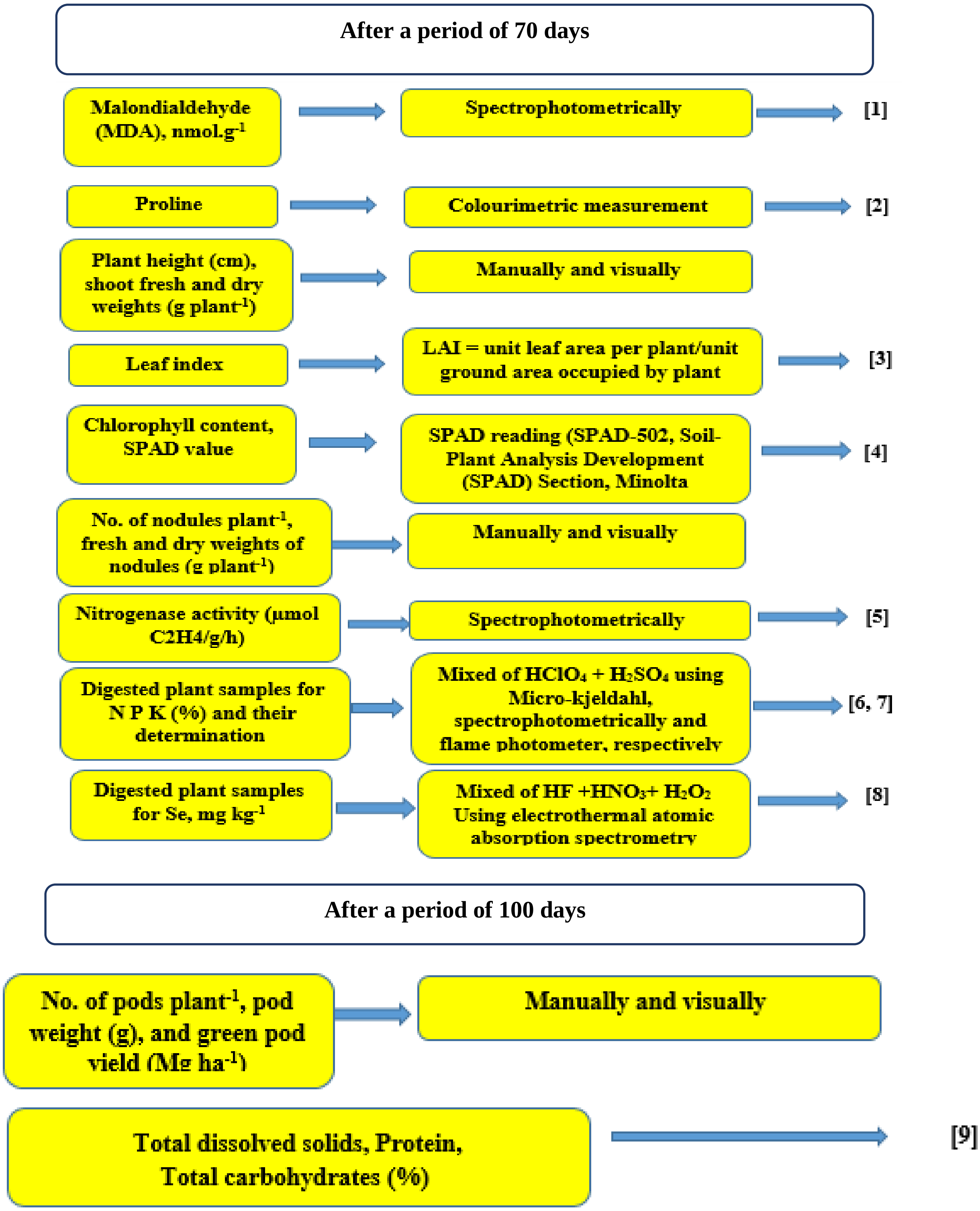

Fig. 1. Methods and references of measurements.

List of refs: **[1]** Ouyang *et al.* (2010), **[2]** Ábrahám *et al.* (2010), **[3]** Adil (2012), **[4]** Castelli *et al.* (1996), **[5]** Hardy *et al.* (1968), **[6]** Peterburgski (1968), **[7]** Walinga *et al.* (2013), **[8]** Kumpulainen *et al.* (1983), **[9]** A.O.A.C (2000)

Table 2. Effect of gypsum, compost and selenium on malondialdehyde (MDA) and proline in leaves of faba bean plant during seasons of 2021/22 and 2022/23 at period of 70 days from sowing.

Treatments	MDA, $nmolg^{-1}$		Proline mg g^{-1} F.W	
	1st season	2nd season	1st season	2nd season
		Soil additions		
T_0	9.51a	9.61a	6.64a	6.71a
T_1	7.47b	7.57b	5.98b	6.06b
T_2	6.11c	6.21c	4.91c	4.99c
T_3	4.99d	5.05d	3.84d	3.89d
LSD at 5%	**0.01**	**0.01**	**0.03**	**0.05**
		Foliar applications		
Se_0	7.37b	7.46b	5.53b	5.59b
Se_1	6.74d	6.82d	5.16d	5.23d
Se_2	6.35e	6.44e	4.95e	5.01e
Se_3	7.04c	7.12c	5.37c	5.44c
Se_4	7.61a	7.70a	5.71a	5.79a
LSD at 5%	**0.03**	**0.03**	**0.12**	**0.03**
		Interaction (TxSe)		
LSD at 5%	**0.05**	**0.05**	**0.24**	**0.05**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

T_0: Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**;** **Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1})

- Performance and productivity

Table 3 demonstrates the significant effects of the studied treatments on growth criteria, including plant height (cm), leaf index, shoot fresh and dry weights (g $plant^{-1}$), and chlorophyll content (SPAD value). While the nodulation parameters as affected by the studied treatments, such as No. of nodules $plant^{-1}$, fresh and dry weights of nodules (g $plant^{-1}$), and nitrogenase activity (µmol C2H4/g/h)are presented in Table 4. Additionally, during the same period in both seasons, the chemical constituents in leaves, such as N, P, K (%) and Se (mg kg^{-1}) **(Table 5),** were significantly affected by application of gypsum, compost, or selenium, either solely or in combinations. The obtained data also indicate that the studied treatments significantly affected pod yield measurements, including the No. of pods $plant^{-1}$, pod weight (g), and green pod yield (Mg ha^{-1}) **(Table 6),** as well as pod bio-constituents, including protein, carbohydrates and TDS % **(Table 7),** after a period of 100 days from sowing faba bean plants during the seasons of 2021/22 and 2022/23. Fig 2 also shows the interaction effect on protein, %.

Regarding soil addition treatments, the combined treatment of gypsum and compost was the most effective in achieving the highest values of plant height (cm), leaf index, shoot fresh and dry weights (g $plant^{-1}$), chlorophyll content (SPAD value), No. of nodules $plant^{-1}$, fresh and dry weights of nodules (g $plant^{-1}$), nitrogenase activity (µmol C2H4/g/h), N, P, K (%) and Se (mg kg^{-1}) at period of 70 days from sowing followed by the treatment of compost alone. The treatment of gypsum alone was less effective, and the control treatment exhibited the lowest values. The significant effect of the studied treatment was reflected on the pod yield measurements, including the No. of pods $plant^{-1}$, pod weight (g), and green pod yield (Mg ha^{-1}),as well as pod bio-constituents, including protein, carbohydrates and TDS (%) after a period of 100 days from sowing. In other words, the trend of productivity traits looks just like the trend of growth criteria.

The selenium treatments had a significant and gradual impact on all the mentioned traits, with an increase observed as the Se rate was increased from 0.0 mgL^{-1} to 5.0 mgL^{-1}, followed by a significant and gradual decrease until the selenium concentration reached 10.0 mgL^{-1}. Notably, the values obtained under the control treatment were superior to those observed under the Se_4 treatment (10.0 mgL^{-1}), indicating that excessive selenium application may have a negative effect on the traits. These findings underscore the importance of identifying the optimal selenium concentration for the species and experimental conditions under consideration. Generally, it can be noticed that the combination of T_3 (compost+ gypsum) and Se_2 (5.0 mgL^{-1}) treatments resulted in the most favorable growth performance and productivity for faba bean cultivation under saline soil conditions.

Table 3. Effect of gypsum, compost and selenium on growth criteria and photosynthetic pigment of faba bean plant during seasons of 2021/22 and 2022/23 at period of 70 days from sowing.

Treatments	Plant height, cm		Leaf area index		Shoot fresh weight, g plant^{-1}		Shoot dry weight, g plant^{-1}		Chlorophyll, SPAD reading	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Soil additions										
T_0	101.11d	104.47d	4.09d	4.13d	96.11d	97.72d	12.64d	12.93d	43.57d	44.04d
T_1	108.87c	112.49c	4.53c	4.58c	106.65c	108.14	15.75c	15.96c	45.14c	45.67c
T_2	116.46b	120.62b	4.79b	4.85b	117.16b	119.12	18.56b	18.90b	46.67b	47.32b
T_3	124.08a	128.59a	5.08a	5.15a	127.61a	129.87	21.33a	21.73a	47.76a	48.42a
LSD at 5%	**0.40**	**0.42**	**0.05**	**0.03**	**0.58**	**0.38**	**0.18**	**0.20**	**0.08**	**0.28**
Foliar applications										
Se_0	111.26d	115.13d	4.55d	4.61d	109.88c	111.71	16.50d	16.13d	45.45d	46.04b
Se_1	114.03b	117.84b	4.69b	4.75b	113.97b	115.38	17.68b	16.13b	46.05b	46.68a
Se_2	115.69a	119.80a	4.76a	4.82a	116.00a	117.81	18.25a	16.13a	46.31a	46.88a
Se_3	112.53c	116.52c	4.62c	4.67c	111.05c	112.81	17.11c	16.13c	45.85c	46.40a
Se_4	109.65e	113.42e	4.48e	4.54e	108.51d	110.84	15.81e	16.13e	45.26e	45.83c
LSD at 5%	**0.31**	**0.32**	**0.05**	**0.05**	**1.28**	**0.53**	**0.18**	**0.21**	**0.17**	**0.53**
Interaction (TxSe)										
LSD at 5%	**0.62**	**0.65**	**0.10**	**0.09**	**2.57**	**1.06**	**0.37**	**0.42**	**0.33**	**1.05**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level .
T_0: Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**;** **Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1})

Table 4. Effect of gypsum, compost and selenium on nodulation parameters of faba bean plant during seasons of 2021/22 and 2022/23 at period of 70 days from sowing.

Treatments	No. of nodules plant^{-1}		F.W of nodules, g		D.W of nodules, g		Nitrogenase activity,µmol C_2H_4/g/h	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Soil additions								
T_0	89.13d	92.07d	9.80d	9.96d	2.73d	2.79d	15.32d	15.69d
T_1	104.87c	109.40c	11.14c	11.32c	3.39c	3.45c	17.01c	17.35c
T_2	122.53b	127.80b	12.58b	12.79b	3.94b	4.01b	18.51b	18.84b
T_3	140.60a	124.87a	14.01a	14.21a	4.50a	4.59a	20.11a	20.55a
LSD at 5%	**2.26**	**1.62**	**0.02**	**0.04**	**0.05**	**0.03**	**0.13**	**0.33**
Foliar applications								
Se_0	111.08d	114.83d	11.63d	11.81d	3.55d	3.61d	17.40d	17.75d
Se_1	117.42b	121.83b	12.15b	12.36b	3.77b	3.85b	18.10b	18.45b
Se_2	120.92a	126.08a	12.45a	12.64a	3.88a	3.96a	18.43a	18.84a
Se_3	114.75c	104.25c	11.87c	12.05c	3.66c	3.74c	17.69c	18.08c
Se_4	107.25e	100.67e	11.32e	11.50e	3.33e	3.40e	17.05e	17.42e
LSD at 5%	**2.27**	**2.47**	**0.04**	**0.04**	**0.04**	**0.02**	**0.09**	**0.19**
Interaction (TxSe)								
LSD at 5%	**4.53**	**4.94**	**0.09**	**0.07**	**0.08**	**0.04**	**0.19**	**0.37**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

T_0: Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**;** **Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1})**.**

Table 5. Effect of gypsum, compost and selenium on chemical constituents in leaves of faba bean plant during seasons of 2021/22 and 2022/23 at period of 70 days from sowing.

Treatments	N,%		P,%		K,%		Se, mg kg^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Soil additions								
T$_0$	3.43d	3.50d	0.332d	0.339d	1.99d	2.01d	2.47d	2.55d
T$_1$	3.74c	3.81c	0.378c	0.384c	2.39c	2.42c	2.64c	2.72c
T$_2$	4.02b	4.10b	0.423b	0.432b	2.75b	2.79b	2.83b	2.93b
T$_3$	4.29a	4.38a	0.471a	0.481a	3.07a	3.11a	3.07a	3.18a
LSD at 5%	**0.05**	**0.05**	**0.002**	**0.002**	**0.05**	**0.04**	**0.04**	**0.02**
Foliar applications								
Se$_0$	3.83d	3.91c	0.392d	0.399d	2.47d	2.50d	0.77e	0.80e
Se$_1$	3.93b	4.01b	0.412b	0.421b	2.63b	2.67b	1.99d	2.05d
Se$_2$	3.99a	4.06a	0.421a	0.429a	2.71a	2.74a	2.96c	3.06c
Se$_3$	3.88c	3.95c	0.400c	0.407c	2.56c	2.59c	3.60b	3.73b
Se$_4$	3.73e	3.80d	0.382e	0.389e	2.39e	2.42e	4.44a	4.59a
LSD at 5%	**0.04**	**0.04**	**0.002**	**0.002**	**0.05**	**0.03**	**0.07**	**0.02**
Interaction (TxSe)								
LSD at 5%	**0.09**	**0.09**	**0.005**	**0.005**	**0.10**	**0.06**	**0.13**	**0.05**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

T$_0$: Without any soil addition (control); **T$_1$:** Gypsum at rate of 7.2 Mg ha^{-1}; **T$_2$:** Compost at rate of 7.2 Mg ha^{-1}**;** **T$_3$:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**;** **Se$_0$:** Without selenium (control); **Se$_1$:** With selenium (2.5 Se mgL^{-1}); **Se$_2$:** With selenium (5.0 Se mgL^{-1}); **Se$_3$:** With selenium (7.5 Se mgL^{-1}); **Se$_4$:** With selenium (10.0 Se mgL^{-1})**.**

Table 6. Effect of gypsum, compost and selenium on pods yield measurements of faba bean plant during seasons of 2021/22 and 2022/23 at period of 100 days from sowing.

Treatments	No. of pods plant^{-1}		Pod weight, g		Green pods yield, Mg ha^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Soil additions						
T$_0$	10.80d	11.87d	15.94d	16.25d	5.10d	5.17d
T$_1$	16.47c	17.73c	18.47c	18.81c	6.92c	7.03c
T$_2$	22.27b	23.53b	20.91b	21.33b	8.32b	8.45b
T$_3$	28.47a	29.27a	23.28a	23.71a	9.50a	9.63a
LSD at 5%	**1.53**	**2.61**	**0.03**	**0.29**	**0.03**	**0.07**
Foliar applications						
Se$_0$	18.25cd	19.25bc	19.11d	19.48d	7.25d	7.35d
Se$_1$	20.25b	22.00a	20.18b	20.55b	7.70b	7.82b
Se$_2$	22.00a	22.50a	20.64a	21.04a	7.90a	8.02a
Se$_3$	19.58bc	20.83ab	19.64c	20.01c	7.50c	7.61c
Se$_4$	17.42d	18.42c	18.67e	19.06e	6.95e	7.05e
LSD at 5%	**1.72**	**1.88**	**0.07**	**0.22**	**0.03**	**0.04**
Interaction (TxSe)						
LSD at 5%	**3.45**	**3.78**	**0.14**	**0.45**	**0.05**	**0.09**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

T$_0$: Without any soil addition (control); **T$_1$:** Gypsum at rate of 7.2 Mg ha^{-1}; **T$_2$:** Compost at rate of 7.2 Mg ha^{-1}**;** **T$_3$:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**;** **Se$_0$:** Without selenium (control); **Se$_1$:** With selenium (2.5 Se mgL^{-1}); **Se$_2$:** With selenium (5.0 Se mgL^{-1}); **Se$_3$:** With selenium (7.5 Se mgL^{-1}); **Se$_4$:** With selenium (10.0 Se mgL^{-1})**.**

Table 7. Effect of gypsum, compost and selenium on bio constituents of faba bean seeds during seasons of 2021/22 and 2022/23 at period of 100 days from sowing.

Treatments	Protein, %		Carbohydrates, %		TDS, %	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
			Soil additions			
T_0	15.33d	15.56d	53.65d	53.92d	2.67d	2.71d
T_1	17.45c	17.74c	54.93c	55.19c	3.15c	3.21c
T_2	19.46b	19.76b	55.77b	56.03b	3.62b	3.68b
T_3	21.40a	21.71a	56.61a	57.13a	4.06a	4.12a
LSD at 5%	**0.06**	**0.28**	**0.37**	**0.10**	**0.03**	**0.07**
			Foliar applications			
Se_0	17.99d	18.29d	54.98c	55.26c	3.28d	3.33d
Se_1	18.75b	19.05b	55.50ab	55.84a	3.48b	3.53b
Se_2	19.24a	19.54a	55.70a	56.04a	3.56a	3.63a
Se_3	18.38c	18.63c	55.31b	55.62b	3.36c	3.41c
Se_4	17.70e	17.97e	54.72c	55.07c	3.20e	3.25e
LSD at 5%	**0.06**	**0.20**	**0.29**	**0.20**	**0.03**	**0.04**
			Interaction (TxSe)			
LSD at 5%	**0.13**	**0.40**	**0.58**	**0.41**	**0.07**	**0.07**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

T_0: Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**; Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1}).

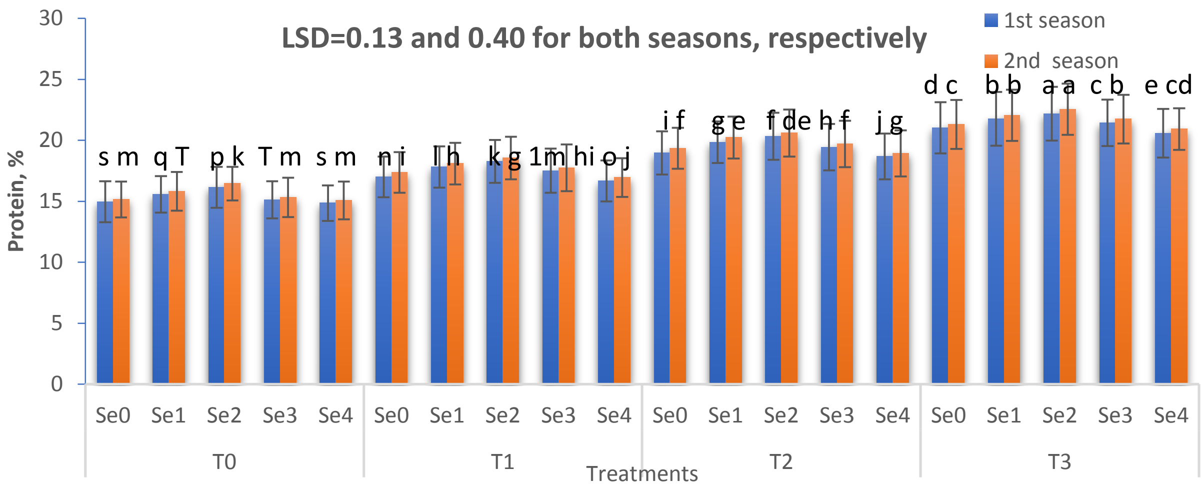

Fig. 2. The interaction effect among gypsum, compost and selenium on protein percentage of faba bean seeds during seasons of 2021/22 and 2022/23 at period of 100 days from sowing.

T_0: Without any soil addition (control); **T_1:** Gypsum at rate of 7.2 Mg ha^{-1}; **T_2:** Compost at rate of 7.2 Mg ha^{-1}**;** **T_3:** Gypsum +compost at rate of 3.6 Mg ha^{-1} for each of them**; Se_0:** Without selenium (control); **Se_1:** With selenium (2.5 Se mgL^{-1}); **Se_2:** With selenium (5.0 Se mgL^{-1}); **Se_3:** With selenium (7.5 Se mgL^{-1}); **Se_4:** With selenium (10.0 Se mgL^{-1}).

4. Discussion

Faba bean plants grown on the studied soil exhibited poor performance and reduced productivity under saline conditions (EC value = 6.26 dSm^{-1}). This might create an unfavorable environment for plant growth by affecting the faba bean plant's ability to take up water and nutrients from the soil **(Yildiz *et al.* 2020).** Salt accumulation in the studied soil might cause an imbalance in the soil's pH, leading to a reduction in soil fertility and inhibiting the faba bean plant's ability to absorb essential minerals such as nitrogen, phosphorusand potassium. Furthermore, the high salt concentration in the studied soil might lead to an increase in oxidative stress on the faba bean plant **(Lalarukh *et al.* 2021).** This occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the faba bean plant's ability to detoxify them **(Lalarukh *et al.* 2022).** The excess ROS might damage the faba plant's cellular components, including membranes, proteins, and DNA, leading to reduced photosynthesis, growth, and yield **(Elsherpiny *et al.* 2022).** In addition, high soil salinity might lead to the accumulation of toxic ions, such as chloride and sodium, in the faba bean plant tissues, further damaging the plant's metabolism and reducing its productivity. The obtained results are in harmony with those of **Ghazi *et al.* (2022).**

Generally, the combination of T_3 (compost+ gypsum) and Se_2 (5.0 mgL^{-1}) treatments resulted in the most favorable growth performance and productivity.It can be interpreted and understood the vital role of this combined treatment as follows.

Regarding proline, when untreated faba bean plants were exposed to soil salinity, they could exert an increase in the ROS production within their tissue, which can cause damage to the plant's cellular components **(Qamer *et al.* 2021**). To counteract the damaging effects of ROS, faba bean plants have developed a sophisticated antioxidant defense system **(Hayat *et al.* 2021).**

The untreated faba bean plants increased theirself-production of non-enzymatic antioxidants (proline) under soil salinity stress conditions as a protective mechanism against oxidative stress **(Cao*et al.* 2020).** In other words, in response to stress conditions, the untreated faba bean plants increased the production of proline to maintain cellular homeostasis and minimize damage caused by ROS. Therefore, the increase in the self-production of antioxidants by the untreated faba bean plants under soil salinity stress conditions is a critical adaptive response that helps to protect the plant's cellular components, maintain cellular homeostasis, and improve their ability to tolerate and survive various environmental stressors ref?. The obtained results are consistent with the findings of **Amer and Hashem (2018**); **El-Ramady *et al.* (2019); Nada *et al.* (2023).**

MDA (Malondialdehyde) is a byproduct of lipid peroxidation, which is a process that occurs when free radicals attack and damage the lipids (fats) in cell membranes **(Sadak*et al.* 2020).** MDA is a highly reactive and toxic compound that damage cellular components such as proteins and DNA. In plants, MDA accumulation is often used as an indicator of oxidative stress caused by salinity stress **(Morales and Munné-Bosch 2019).** When plants experience oxidative stress, lipid peroxidation can occur, leading to an increase in MDA levels **(Khoubnasabjafari and Jouyban 2020).** By scavenging free radicals, the soil addition (either compost, gypsum or their combination) and Se foliar application at all studied rates, except 10 mgL^{-1}, can help to prevent lipid peroxidation and reduce the accumulation of toxic compounds such as MDA in plant cells. This helps to maintain cellular homeostasis, improve faba bean plant growth and productivity, and enhance their ability to tolerate and adapt to salinity stress conditions. The findings agree with the obtained result of **Othman *et al.* (2021).**

The superiority of compost may be attributed to its ability in increasing the amount of organic matter in the soil, which can improve soil structure and water-holding capacity (**Ghazi*et al.* 2022 b).**This can reduce the negative impact of sodium salts on soil structure **(Farid *et al.* 2020)** and help to improve soil fertility over time **(Tolba *et al.* 2021; Farid *et al.* 2022).** Compost contains a range of essential nutrients, such as nitrogen, phosphorus, and potassium, which can help for improving faba bean growth and productivity in salt-affected soils. Also, it contains micronutrients, which can help to correct nutrient deficiencies that may be present in salt-affected soils. On the other hand it can promote microbial activity in the soil, which can break down organic matter and release nutrients that are locked up in the soil. All these factors may improve nutrient availability for plants and help to restore soil health. Also, it can help to reduce soil salinity by promoting soil aggregation that facilitate the leaching of salts from the soil, and reduce their impacts on plants (**Hussein *et al.* 2022**; **Elsherpiny *et al.* 2023**).

Agricultural gypsum can play a significant role in the reclamation of salt-affected soils, particularly sodic soils **(Abo El-Ezz *et al.* 2020).**It is a calcium sulfate compound that can improve soil structure, increase water infiltration, and reduce soil salinity levels **(Sheikh *et al.* 2022).**Moreover, it reduces soil salinity levels by replacing exchangeable sodium ions with calcium ions. The calcium in gypsum may displace the sodium on the studied saline soil particles, which can reduce soil dispersion and improve soil structure. Agricultural gypsum may improve water and nutrient availability for plants and promote healthy root growth (**Ghazi *et al.* 2021).** Agricultural gypsum can improve soil structure by increasing soil aggregation and reducing soil crusting (**El-Ramady*et al.* 2022).**This can improve soil porosity and water infiltration, which can reduce water logging and soil erosion. The improved soil structure can also increase root penetration and nutrient uptake, which can enhance plant growth and productivity. Also, agricultural gypsum can increase the availability of essential nutrients such as phosphorus, sulfur, and calcium, which can be limited in salt-affected soils. These may be the real reasons for enhancing faba plant growth and productivity, under gypsum treatments compared to the control one. Overall, the combined treatment of compost and gypsum at a rate of 3.6 Mg ha^{-1} is superior to application of gypsum or compost alone at a rate of 7.2 Mg ha^{-1}due to its ability to improve soil structure, enhance soil fertility, and increase nutrient availability to plants, leading to improved plant growth and productivity **(Luiz *et al.* 2022).**

The superiority of the combined treatment of compost and gypsum versus each solely may be attributed to various reasons. Firstly, gypsum is a soil amendment that can improve soil structure and increase the availability of calcium and sulfur to plants (**Ghazi *et al.* 2021).** However, it has a limited ability to provide essential plant nutrients such as nitrogen, phosphorus, and potassium. On the other hand, compost is a rich source of organic matter and nutrients, including nitrogen, phosphorus, and potassium, that can improve soil fertility and enhance plant growth (**Ghazi *et al.* 2022 b).** By combining gypsum and compost, the soil structure can be improved, and the soil is enriched with organic matter and essential plant nutrients, leading to an increase in plant growth and productivity **(Tolba *et al.* 2021; Farid *et al.* 2022).** This combined treatment might improve water retention and drainage in the soil, further enhancing plant growth. Secondly, when these amendments (gypsum and compost) are applied together, they might complement each other's benefits. Finally, the combined treatment of compost and gypsum might also enhance the activity of soil microorganisms, leading to an increase in nutrient cycling and the breakdown of organic matter. This can result in the release of plant-available nutrients, further improving plant growth and productivity. At low concentrations (2.5 and 5.0 mg L^{-1}), selenium can protect plant cells from oxidative damage caused by ROS. Selenium at low concentrations (2.5 and 5.0 mg L^{-1}) can help to maintain cell integrity and improve faba bean plant health. Also, it can enhance the plant's natural defense mechanisms against salinity stress. It can help to activate antioxidant enzymes like superoxide dismutase (SOD) and catalase (CAT), which can neutralize ROS and protect plant cells from damage. On the other hand, it can help to improve plant water use efficiency, reduce salt accumulation in faba bean plant tissues, and detoxify heavy metals, allowing plants to grow in otherwise inhospitable conditions. Generally, it can be said that Selenium may accumulate in plant tissues, providing a defense against salt stress. On the contrary, at high concentrations (7.5 and 10.0 mg L^{-1}), selenium toxicity on faba bean plants appeared. Selenium is an essential micronutrient for plant growth, but it can become toxic to plants when applied at high concentrations. This is because plants can only tolerate a certain amount of selenium before it starts to interfere with essential physiological processes. When selenium is applied at high concentrations, it can accumulate in plant tissues and cause a range of toxic effects, including chlorosis (yellowing of leaves), necrosis (death of plant tissue), stunted growth, and reduced yields. Selenium can also interfere with the uptake and transport of other essential nutrients, such as sulfur and phosphorus, which can further disrupt plant growth and development. The findings are in agreement with those of **Mahmoud *et al.* (2023).**

5. Conclusion

Based on the results presented, it can be concluded that under salt-affected soil conditions, the combined treatment of gypsum and compost was the most effective in improving soil quality and promoting faba bean plant growth. The addition of selenium also had a significant impact on the studied traits, but its effect was dose-dependent, with the highest values obtained at 5.0 mgL^{-1} and a decrease observed at higher concentrations. Overall, while selenium is an essential nutrient for plants, it is important to apply it at appropriate concentrations to avoid toxicity and ensure optimal plant growth and health.

Therefore, it is recommended that farmers and gardeners dealing with salt-affected soil use a combination of gypsum and compost to improve soil quality and plant growth. Additionally, when adding selenium to the plant, it is crucial to consider the dose and avoid excessive application, as this may have a negative impact on plant growth, especially under salt-affected conditions. Regular monitoring of soil quality and adjusting the application of additives accordingly is essential to maintain a healthy and productive growing environment, particularly in salt-affected soils.

Conflicts of interest

Authors have declared that no competing interests exist.

Formatting of funding sources: The research was funded by the personal efforts of the authors.

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