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Arbuscular Mycorrhizal Fungi Improve Selenium and Cobalt Biofortification in Snap Bean

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ALTHOUGH selenium (Se) and cobalt (Co) are important trace elements in humans, their consumption from food remains generally inadequate throughout the world. Therefore, Se and Co biofortification is a common method for increasing selenium and cobalt intake and maintaining human health. Arbuscular mycorrhizal fungi (AMF) colonization show many roles, remarkably enhanced plant nutrition uptake, growth and yield, and abiotic stress resistance. Such roles can be employed to biofortify snap bean with Se or Co and improve plant growth and yield. A field experiment was carried out during 2020/2021 and 2021/2022 seasons at the Experimental Vegetable Farm of the Horticulture Department, Faculty of Agriculture, Ain Shams University, Qalyubia Governorate, Egypt. The study was carried out to investigate the effects of Se and Co foliar application and AMF inoculation on the growth, yield, and quality of snap bean plants grown in a clay soil. Results showed that the interaction between the mycorrhizal inoculation and foliar application of selenium at 10 µM or cobalt at 100 µM led to improvements in all vegetative growth parameters, SPAD readings, minerals content, and yield components and produced snap bean pods biofortified with selenium or cobalt in both growing seasons. In conclusion, AMF can be utilized to enhance Se and Co biofortification during the production of snap bean.

Keywords: *Phaseolus vulgaris* L., Selenium, Cobalt, Biofortification, AMF

Introduction

Nutritional deficiency is a common global concern in most developing countries, due to a lack of various resources and a growing population. Nutritional deficiencies are reported to affect 2 billion people worldwide (Van Der Straeten et al., 2020). The process of improving nutrient bioavailability in the edible parts of crop plants via agronomic practices is termed as biofortification (Rana et al., 2012). Biofortification is an effective way used to boost the nutritional value, especially beneficial elements in food crops. Beneficial elements are mineral elements that are non-essential for plants but have a role in stimulating growth and have beneficial effects at very low concentrations despite not being required for plants to complete their life cycle (Piccolo et al., 2021). Selenium, and cobalt are considered beneficial elements for plants (Pilon-Smits et al., 2009) and of vital importance to human health. However, these two elements are limiting in the diets of much of the world's population, particularly in Africa, Asia, and Latin America. Enhancing the bioavailability of these elements in widely consumed food crops like snap bean is an important strategy to overcome trace-element deficiencies in these crops and improve human health.

Selenium (Se) is a common metalloid nutrient that is vital for people and animals in low concentrations, but hazardous in high concentrations (Sors et al., 2005). In humans, Se plays a key role in immunity, antioxidant defense, and redox homeostasis through functioning as

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the catalytic core of numerous selenoproteins (Gupta and Gupta, 2016). The World Health Organization (WHO) recommends people to obtain ~50-55 µg of selenium per day from their diet to maintain good health. However, in some countries including Egypt, a selenium deficiency in the diet has been observed. According to reports, 0.5-1.0 billion people worldwide suffer from Se deficiency (Lopes et al., 2017) which has been associated with health disorders like Keshan disease, heart disease, Kashin-Beck disease, and hyperthyroidism, and increase the risk of cancers (Shahid et al., 2018).

Se in soil can pass into food chain via plant uptake, and humans obtain most of their Se from the food chain (Yu et al., 2011). In addition, low concentrations of Se in soil can upregulate the production of higher plant enzymes such as peroxidases and reductases, and protect plants from abiotic stresses (Wang et al., 2019), and have favorable effects on plant growth and yield (White, 2018) of many vegetable crops including common bean (Corbo et al., 2018; Moussa and Hassen, 2018; Hmood et al., 2022), peas (Žitná et al., 2018) and lettuce (Abdalla et al., 2024). Therefore, in agriculture, Se biofortification is one of the effective strategies to improve plant Se content to meet human health requirements (Zhang et al., 2014).

Cobalt (Co) is one of the beneficial elements presents in the Earth's crust in the form of erythrite [Co_3 $(AsO_4)_2$], cobaltite (CoAsS) and smaltite ($CoAs_2$) (Nagajyoti et al., 2010) with a concentration of about 40µg/g. Cobalt is required as an important component for the synthesis of vitamin B12, which is necessary for human and animal nutrition (Srivastav et al., 2022). Although Co is not considered an essential element, it is considered as a good element for plants (Komeda et al., 1997). Co is a component of many enzymes and coenzymes, and promotes plant growth and development at low concentrations, but at higher concentrations it disrupts many physiological, biochemical and metabolic processes (Akeel and Jahan, 2020; Hu et al., 2021). Co promotes various developmental processes such as stem cotyledonary petiole elongation, hypocotyle opening, leaf expansion, and bud formation (Hu et al., 2021). Excessive Co-toxicity leads to various problems such as loss of dry weight, chlorosis, premature leaf closure, leaf detachment, and reduced active transport (Mahey et al., 2020). The Co biofortification is one of the effective method to improve plant Co content to meet human health requirements.

These biofortified plants aim to diminish the socio-economic impact of malnutrition and are considered as alternative plants in developed countries. Furthermore, recent understanding of the interactions between soil microorganisms such as arbuscular mycorrhizal fungi (AMF) and plant roots in the rhizosphere has prompted research into the application of soil microbial communities in crop biofortification. Several studies have shown that AMF aid in the uptake of many nutrients by plants. AMF are an important soil microbial community and colonize more than 80% of terrestrial plant roots and help in plant growth, nutrition, and tolerance for diseases (He et al., 2017a,b) by increasing the absorptive root surface through hyphae, thus helping host plant acquire water and nutrients. Meanwhile, there are some studies about the effects of AMF on the uptake and accumulation of Se and Co by plants, which are controversial. Nevertheless, the mechanisms related to the interaction of AMF and Se or Co uptake in the soil systems are still not clear.

Therefore, this study may provide insights into the effects of Se and Co foliar application and AMF inoculation on plant growth, nutrient uptake and fruit yield and provide a basis to explore methods to use to produce high-quality snap bean fruits enriched with Se or Co.

Materials and Methods

Experimental site

A field experiment was conducted during the two growing seasons of 2020/2021 and 2021/2022 at the Experimental Vegetable Farm of the Horticulture Department (30° 06′ 46″ N, 31°14′ 37″ E), Faculty of Agriculture, Ain Shams University, Qalyubia Governorate, Egypt. The study was carried out to investigate the effects of Se and Co foliar application and AMF inoculation on the growth, yield, and quality of snap bean plants grown in a clay soil.

Plant material and study design

Snap bean cv. Paulista seeds were obtained from TechnoGreen Import Corporation. Before sowing, the seeds were treated with the commercial fungicides Amisto and Prevex-N which contain active Azoxystrobin 25% and Propamocarb Hydrochloride 72.2 %, respectively.

The field was divided into rows with 70 cm width and 4 m long. The seeds were sown on September 13th and 15th for the first and second growing seasons, respectively, in hills at 20 cm apart on one side of the rows. In each hill, two seeds were cultivated. Each experimental plot area was 8.4 m^2 which comprised 3 rows. Furrow irrigation was used.

A split-plot design with three replications was used, where the main plots were designated for mycorrhizal-treated bean seedlings, and the sub-main plots were randomly assigned for selenium and cobalt spraying.

Treatments

The bean seedlings were inoculated with the AMF as a mixture of *Glomus* spp fungi obtained from the Microbial Wealth Center at the Faculty of Agriculture of Ain Shams University. Each plot received 200 ml of AMF inoculum containing 106 cells per 1 ml fungal suspension. The experiment included fourteen treatments: inoculation and non-inoculation of bean seedlings with AMF, each later sprayed with either sodium selenate solution at 5, 10, and 15 µM, or cobalt sulfate solution at 100, 200, and 300 µM. Distilled water was sprayed as a control treatment. The foliar treatments were applied twice, at 20 and 40 days after sowing. Before sunset, the plants are thoroughly sprayed with a hand-held sprayer to ensure complete coverage of all plant foliage with selenium or cobalt solutions. An equivalent volume of distilled water was sprayed on the control plots. In both seasons, all agronomic practices such as fertilization, weeding, irrigation, and pest control were regularly carried out following the Egyptian Ministry of Agriculture guideline for snap bean cultivation.

Data recorded

Vegetative growth parameters

At 50 days following planting, a random sample of five plants was selected from the middle row of each experimental plot to collect the plant vegetative characteristics. The plants of the samples were uprooted and immediately transferred to the lab to measure plant length, and number of branches. The fully expanded fourth leaf from the plant top was used to measure Leaf area using Koller's equation (1972) through the relation of the area to leaf fresh weight.

$$\text{Leaf area} = \frac{\text{Disk area x number of disks x fresh weight of leaves}}{\text{Fresh weight of disks}}$$

Number of leaves per plant was counted. The plants were weighed to record the plant fresh weight and were then placed in an oven at 70 °C until reaching constant weight to record the plant dry weight. and plant fresh and dry weights were recorded.

Leaf greenness (SPAD readings)

A portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan) was used to measure the leaf greenness of the plants. SPAD-502 chlorophyll meter is a non-destructive method, which can be used to estimate total chlorophyll amounts in leaves of plants (Neufeld et al., 2006). For each plant, the fourth completely fully expanded leaves of randomly five plants per replicate were selected, and readings were taken at four locations on the leaf; two on each side of the midrib, and then averaged (Khan et al., 2003).

Leaf mineral analysis

For elemental analysis, leaf samples from the fourth upper leaf were taken from 50 days old plants and oven-dried at 70 °C until constant weight. The dried matter was ground into a fine powder using a high-speed stainless-steel miller. A half gram of the powder was taken and digested using a mixture of sulphuric acid (H_2SO_4 98%) and hydrogen peroxide (H_2O_2 30%) as described by Thomas et al. (1967). All the studied elements were assayed in the digested plant samples. The total nitrogen was estimated according to Chapman and Patt (1982). Phosphorous, potassium, calcium, and magnesium were estimated using inductively coupled plasma-optical emission spectrometry (ICP-OES, Varian Inc., Vista MPX) as reported by Rodushkin et al. (1999). All of these mineral elements were estimated in the Central Soil and Water Unit Analysis Laboratory, Faculty of Agriculture, Ain Shams University, Egypt.

Green Pod Yield

Green pods were harvested during the growing season, counted, and weighed to record number of pods/plant, and average pod yield per plant (g).

Total Carbohydrates and Fibres in Pods

In each season, a random sample of 30 green pods from each treatment was used to quantify total carbohydrates and fibres. Total carbohydrates and fibres were quantified in dried pods using the methods outlined by Shaffer and Hartmann (1921) for carbohydrates and by A.O.A.C. (2012) for fibres.

Selenium and Cobalt Contents in Pods

Selenium, and cobalt in pods were assayed using inductively coupled plasma-optical emission spectrometry (ICP-OES, Varian Inc., Vista MPX) as reported by Rodushkin et al. (1999). These mineral elements were estimated in the Central Soil and Water Unit Analysis Laboratory, Faculty of Agriculture, Ain Shams University, Egypt.

Statistical analysis

Data obtained were subjected to a statistical analysis of variance procedure of two-way ANOVA using the package of the CoStat program (version 6.303, CoHort Software, USA) based on a split plot design. Significant differences among treatment means were estimated based on the Duncan's multiple range test (Waller and Duncan, 1969) at P≤0.05 level of probability.

Results

Vegetative growth parameters

Mycorrhizal inoculation enhanced all measured vegetative growth parameters, including plant length, number of branches and number of leaves per plant, leaf area, and fresh and dry weights, in both seasons under the study (Tables 1 and 2). Notably, the inoculated plants exhibited a significant increase in leaf area and fresh and dry weights compared to non-mycorrhizal plants in both growing seasons.

Foliar applications of selenium (Se) or cobalt (Co) generally improved all measured growth parameters in both growing seasons compared to the control plants. Se applied at 15 µM and Co at 100 µM positively influenced plant length, number of leaves, and leaf area.

Additionally, Co application at 100 µM increased the number of branches and gave the highest fresh weight compared to the respective control plants in both growing seasons. Moreover, Se at 10 µM and Co at 100 µM increased dry weight compared to the respective control plants in both growing seasons.

Regarding the interaction between the mycorrhizal inoculation and foliar application of selenium or cobalt, the combinations led to improvements in all vegetative growth parameters compared to their respective control in both growing seasons. The simultaneous application of arbuscular mycorrhizal fungi (AMF) and application of selenium (15 µM) or cobalt (100 µM) significantly enhanced plant length, number of branches, number of leaves, and leaf area compared to the respective control plants in both growing seasons. Additionally, the application of selenium at 10 µM, cobalt at 100 or 200 µM in conjunction with mycorrhizal inoculation significantly improved fresh and dry weights of vegetative growth compared to the respective control plants in both growing seasons.

SPAD readings

The data in Table 2 demonstrate that mycorrhizal inoculation positively impacted SPAD readings during both seasons. Foliar applications of selenium or cobalt increased SPAD readings compared to the control plants in both study seasons. When examining the interaction between mycorrhizal inoculation and foliar applications of selenium or cobalt, mycorrhizal inoculation resulted in improved SPAD readings compared to their control plants in both seasons.

Leaf mineral content

The data presented in Table 3 indicate that mycorrhizal inoculation significantly increased the concentrations of N, P, K, Ca, and Mg in both growing seasons.

Foliar applications of selenium or cobalt significantly increased the mineral content of leaves compared with the check plants in both of the investigated seasons. Selenium applied at 10 µM and cobalt at 100 µM led to enhanced levels of nitrogen, phosphorus, potassium, and magnesium in plants compared to the respective control plants in both growing seasons. Cobalt applied at 100 µM resulted in the highest significant increase in calcium content compared to the control check in both seasons (Table 3). However, cobalt applied at 200 µM improved the levels of nitrogen, phosphorus, and magnesium compared to the control group in both seasons.

Concerning the interplay between mycorrhizal inoculation and foliar applications of selenium or cobalt, selenium applied at 10 µM in combination with mycorrhizal inoculation resulted in increased levels of nitrogen, phosphorus, calcium, and magnesium in plants compared to the respective controls in both growing seasons. Additionally, cobalt supplementation at 100 µM positively influenced the mineral content measured in the leaves. Also, the addition of cobalt at 200 µM led to improved nitrogen, phosphorus, and magnesium levels in leaves compared to the control plants in both investigated seasons.

Number of pods and plant yield

The data presented in Table 4 reveal that mycorrhizal inoculation significantly increased the number of pods and plant yield in both growing seasons. Additionally, foliar applications of selenium or cobalt positively influenced these two parameters. Among the various treatments, cobalt supplementation at 100 µM yielded the most significant improvements in the number of pods and plant yield in both study seasons. Selenium applied at 10 µM and cobalt at 100 µM also positively enhanced the number of pods compared to the control. Furthermore, selenium applied at 10 or 15 µM and cobalt at 200 µM resulted in increased plant yield in both growing seasons compared to the control.

An interaction between mycorrhizal inoculation and foliar applications of selenium or cobalt was observed. Specifically, the combination of selenium at 10 µM or cobalt at 100 µM and 200 µM with mycorrhizal inoculation led to a significant increase in the number of pods compared to the control. Additionally, selenium applied at 10 or 15 µM or cobalt at 100 or 200 µM in conjunction with mycorrhizal inoculation resulted in enhanced plant yield compared to their respective control.

Total carbohydrates and fibres

As shown in Table 5, mycorrhizal inoculation significantly increased the total carbohydrate content in the pods during both growing seasons. However, there was no significant difference in the fibre content.

Foliar applications of selenium or cobalt increased the total carbohydrates and fibre content in plants during both growing seasons. Selenium applied at a concentration of 10 µM or cobalt at 100 µM resulted in the highest significant increases in total carbohydrates. However, neither selenium nor cobalt had a significant effect on fibre content during the growing season.

The combination of mycorrhizal inoculation and foliar applications of selenium or cobalt led to a significant increase in total carbohydrates in plants compared with the check plants. The combined application of selenium (at 10 or 15 µM) and cobalt (at 100 µM) with mycorrhizal inoculation significantly increased total carbohydrate content in plants compared to the control plants. However, there was no significant interaction between mycorrhizal inoculation and foliar applications on the fibre content.

Se and Co content in pods

The data presented in Table 6 demonstrate that mycorrhizal inoculation significantly increased Se content in pods and Co content in pods during both growing seasons.

Selenium applied at 10 or 15 µM resulted in the highest substantial increases of selenium content in the pods in both study seasons. Meanwhile, cobalt applied at 300 µM significantly elevated pod cobalt content in both seasons.

Regarding the interaction between mycorrhizal inoculation and foliar application of selenium or cobalt, selenium at 10 µM and mycorrhizal inoculation together produced the highest selenium levels in pods, while cobalt at 300 µM and mycorrhizal inoculation enhanced pod cobalt content.

Discussion

Biofortification presents a promising approach to augment the micronutrient content of staple crops, thereby mitigating malnutrition and micronutrient deficiencies. A potential supplementary strategy to enhance micronutrient concentrations crop plants through biofortification lies in the utilization of agriculturally significant microorganisms (Upadhayay et al., 2022; Avnee et al., 2023). In this regard, mycorrhizal fungi inoculation could be employed to this aim (Upadhayay et al., 2022).

Mycorrhizal inoculation has demonstrated significant improvements in snap bean (*Phaseolus vulgaris* L.) growth parameters in our study compared to the control in both growing seasons, underscoring its potential to enhance agricultural productivity and sustainability. Studies have revealed that the co-inoculation of arbuscular mycorrhizal fungi (AMF) can significantly improve root nodule formation and plant growth metrics. The improved nodule formation is attributed to the enhanced nutrient acquisition facilitated by mycorrhizal fungi, which extend the root system's ability to absorb water and nutrients, particularly phosphorus (Tajini and Drevon, 2012; Beltayef et al., 2020). Also, mycorrhizal inoculation has been shown to significantly increase phosphorus uptake in common beans (Tajini and Drevon, 2012; Beltayef et al., 2020).

This increased phosphorus availability directly correlates with improved growth parameters, including shoot and root biomass, leaf area, and ultimately, yield (Abdel-Fattah et al., 2016; de Souza Buzo et al., 2022). These findings align with previous research by Wahab et al. (2023) and St. Subaedah et al. (2024) who reported similar positive effects of mycorrhiza on plant growth and yield. Also, a study demonstrated that common beans inoculated with AMF exhibited improved growth (Beltayef et al., 2020).

Research has shown that AMF inoculation can lead to increased chlorophyll concentrations in various plant species, including common beans. For instance, Gunes et al. (2023) reported that AMF inoculation resulted in higher leaf chlorophyll content in *Capsicum annuum* compared to non-inoculated plants, suggesting a similar trend could be expected in common beans. Furthermore, Erdinc et al. (2017) found that different genotypes of common beans exhibited variations in response to AMF inoculation, with some showing significantly enhanced chlorophyll levels, which directly correlates with improved SPAD readings. This is consistent with findings from Tajini et al. (2011) who noted that co-inoculation with AMF and *Rhizobium tropici* improved phosphorus use efficiency and chlorophyll content in common beans, further supporting the role of AMF in enhancing photosynthetic efficiency. Additionally, AMF play a crucial role in phosphorus nutrition, which is vital for chlorophyll synthesis (Hoeksema et al., 2010).

Mycorrhizal colonization directly influences mineral nutrition by enhancing nutrient acquisition and indirectly by modifying transpiration and the rhizosphere microbiome (Marschner and Dell, 1994). Our findings align with those of Abdullahi and Sheriff (2013) who observed that mycorrhiza effectively mobilizes and transports phosphate, nitrogen, potassium, magnesium, and other elements to the plant. Moreover, de Souza Buzo et al. (2022) emphasized that mycorrhizal inoculation significantly improved the nutritional status of common beans. This is particularly advantageous in nutrient-deficient soils, where mycorrhizal fungi can access nutrients that are otherwise inaccessible to the plant roots alone. For instance, previous studies have shown that inoculation with arbuscular mycorrhizal fungi (AMF) significantly enhanced nitrogen absorption in snap beans, as these fungi facilitate soil organic matter decomposition and nitrogen uptake from the soil (Bücking and Kafle, 2015; Beltayef et al., 2020). Moreover, mycorrhizal fungi have been found to elevate phosphorus content in the leaves of snap beans, a result attributed to their colonization and infectivity (Beltayef et al., 2020). Additionally, research indicates that these fungi also enhance the uptake of potassium, calcium, and magnesium. Also, a study demonstrated that mycorrhizal inoculation led to increased levels of potassium, calcium, and magnesium in snap bean plants, emphasizing the broad range of nutrient enhancement provided by mycorrhizal associations (de Souza Buzo et al., 2022).

Mycorrhizal inoculation has been extensively studied for its potential to augment the yield of snap bean plants (*Phaseolus vulgaris* L.). Research consistently demonstrates that mycorrhizal inoculation can significantly increase yield by improving nutrient absorption and overall plant health. Furthermore, Abdel-Fattah et al. (2016) emphasized that the application of AMF in conjunction with reduced NPK fertilizer levels resulted in substantial improvements in the growth and yield components of common bean plants. This study highlights the potential of mycorrhizal technology to optimize nutrient use efficiency, enabling lower fertilizer inputs while maintaining or enhancing crop yields. Similarly, Beltayef et al. (2020) reported that co-inoculation with AMF improved crop yield and quality, reinforcing the notion that mycorrhizal associations can be advantageous in various agricultural settings. Moreover, a positive correlation between soil mycorrhizal potential and the natural mycorrhization rates of common beans, suggesting that the presence of native AMF in the soil can enhance the overall yield of snap beans by facilitating better nutrient uptake (Ndeko et al., 2024). Additionally, Garcia et al. (2019) observed that diverse microbial inoculations, including AMF, positively influenced snap bean growth and yield.

Research indicates that mycorrhizal inoculation can enhance the nutritional quality of snap bean seeds. Inoculation of black turtle beans with mycorrhizal fungi enhanced seed nutritional quality, which is critical for addressing nutrient deficiencies in populations reliant on this staple crop. This enhancement is often linked to improved carbohydrate accumulation and fibre content, as mycorrhizal fungi facilitate better nutrient uptake, particularly phosphorus, which is essential for carbohydrate metabolism (Abdel-Fattah et al., 2016, Carrara et al. 2023). Moreover, studies have shown that mycorrhizal colonization can significantly affect the total carbohydrate content in common beans. For example, Abdel-Fattah et al. (2016) reported that mycorrhizal plants exhibited higher concentrations of total carbohydrates compared to non-mycorrhizal plants, particularly under varying nutrient conditions. The interaction between mycorrhizal fungi and common beans can lead to changes in the plant's metabolic pathways, promoting the synthesis of structural carbohydrates that contribute to dietary fibre (Nanjareddy et al., 2017). Likewise, Shinde and Thakur (2015) observed increased total carbohydrates and protein content in mycorrhizal pea plants compared to the control.

The symbiotic relationship between mycorrhizal fungi, particularly arbuscular mycorrhizal fungi (AMF), and plants significantly impacts the absorption of essential nutrients, including selenium and cobalt. For instance, AMF inoculation has been shown to increase the accumulation and speciation of selenium in various plant species, suggesting their role in improving the bioavailability of selenium in the soil (Yu et al., 2011). The mechanisms underlying this enhancement include the activation of nutrient transport pathways and the modification of root architecture, which collectively increase the surface area for nutrient absorption (Smith and Smith, 2011). Furthermore, AMF can influence the chemical forms of selenium in the rhizosphere, making it more accessible to plants (Golubkina et al., 2019). Similarly, AMF has been shown to enhance the translocation of cobalt from roots to shoots, thereby improving the overall nutrient profile of the plant (Ambrosini et al., 2015). However, it is essential to note that excessive cobalt concentrations can inhibit mycorrhizal function, highlighting the importance of maintaining balanced soil nutrient levels to optimize the benefits of mycorrhizal associations (Bano and Ashfaq, 2013).

The exogenous application of selenium or cobalt to plant leaves demonstrated beneficial effects on various metabolic processes (Lyons et al., 2009) The foliar application of selenium significantly promoted vegetative growth parameters in this study. These findings align with previous research on common bean (Hmood et al., 2022). Selenium's growth-stimulating effects are likely attributed to its antioxidant properties, as evidenced by reduced lipid peroxidation, H_2O_2 and superoxide radical production, coupled with increased antioxidant enzyme activity (Saffaryazdi et al., 2012), while the influence of selenium on phytohormone balance and polyamine content cannot be entirely ruled out, selenium-treated potato plants exhibited higher putrescine levels (Turakainen et al., 2008). Polyamines play crucial roles in various plant growth and developmental processes, including cell division, embryogenesis, and floral development (Kakkar and Sawhney, 2002).

It was observed that the SPAD readings of the leaves increased in the present study, which is in agreement with the positive effects of Se treatment in delaying the loss of chlorophyll in senescing *Vicia faba* plants (Moussa and Ahmed, 2010). The increase in chlorophyll of snap bean leaves may be attributed to Se effect over protection of chloroplast enzymes and thus increasing the biosynthesis of photosynthetic pigments (Pennanen et al., 2002). In addition to enhancing chlorophyll content, selenium has been shown to improve the antioxidant defense mechanisms in common beans. Hmood et al. (2022) noted that foliar applications of selenium significantly increased the antioxidant enzyme activities, which help in reducing oxidative stress and preserving chlorophyll integrity.

The findings demonstrated a significant enhancement in foliar nutrient concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in snap bean plants following foliar applications of selenium. In line with these results, Hegedűsová et al. (2021) reported a neutral effect of selenium on calcium uptake but a decrease in phosphorus content in cabbage plants. Conversely, Matraszek and Hawrylak-Nowak (2009), documented an increase in phosphorus content in plants grown in the presence of selenium. Enhanced selenium fertilization led to higher selenium concentrations in potatoes (Poggi et al., 2000; Turakainen et al., 2008).

Yield is influenced by numerous physiological and biochemical processes that are highly sensitive to selenium availability. Results showed that selenium supplementation significantly boosted plant yield in both growing seasons compared to the control plants. Also, foliar application of selenium increased common bean yield. The positive impact of selenium application at suitable concentrations on plant growth has been well-established (Hmood et al., 2022). The observed enhancement in plant growth traits at a lower selenium dose may be attributed to a higher rate of photosynthesis, which is directly correlated with carbohydrate production (Tao et al., 2023). The observed improvements in vegetative growth parameters, yield, and yield quality attributes can likely be attributed to selenium's role in regulating reactive oxygen species (ROS) levels within plant cells, particularly in mitochondria and chloroplasts where electron transport occurs (Zorov et al., 2014). Selenium also regulates the quantity and activity of antioxidant enzymes such as glutathione peroxidase, glutathione reductase, superoxide dismutase, ascorbate peroxidase, and catalase, as well as metabolites like glutathione and ascorbate. This enhanced antioxidant capacity leads to reduced lipid peroxidation, resulting in improved ROS scavenging capabilities (Feng et al., 2013). The positive impact of selenium on antioxidant activity also contributes to enhanced photosynthesis, leading to increased carbon assimilation (Ekanayake et al., 2015). Additionally, selenium supplementation increased the accumulation of osmotically active molecules like total free amino acids and protein (Nawaz et al., 2016). Furthermore, selenium enhanced nutrient uptake (Feng et al., 2009), stimulated starch accumulation in chloroplasts, and improved root activity, ultimately leading to increased water uptake (Proietti et al., 2013) and thus improved the yield. Also, Hmood (2022) demonstrated that selenium application can positively impact metabolic processes, including carbohydrate and protein synthesis, thereby enhancing the nutritional value of beans. Similarly, found that selenium can improve the chemical composition of snap bean pods, leading to increases in total carbohydrates and fibre content (Baddour and Attia, 2021)

Cobalt, on the other hand, is primarily essential for nitrogen fixation in leguminous plants, contributing to plant growth and development. The present study demonstrated that foliar cobalt application enhanced the growth parameters of snap beans. Similarly, Gad et al. (2013) and Kandil et al. (2013) reported similar positive effects of cobalt on the vegetative growth of various crops, including soybeans, faba beans, and others. While cobalt's direct metabolic role in plants remains unclear, its application has been shown to promote several developmental processes, including stem and coleoptile elongation, leaf disc expansion, and bud development, as reported by Ibrahim et al. (1989). Additionally, cobalt can influence nodulation, leading to improved plant growth and yield. However, excessive cobalt levels may have adverse effects on the rhizosphere bacterial population, potentially hindering nodulation and reducing crop performance (Akeel and Jahan, 2020). Also, cobalt application to leguminous plants has been shown to enhance chlorophyll content, growth rate, and the number of branches and leaves (Hu et al., 2021).

Additionally, Co application has been linked to improved photosynthesis and increased levels of protein, sugar, and other carbohydrates in both legumes and non-leguminous plants (Hu et al., 2021). Due to the lack of identified bioactive forms of cobalt in plants, the precise mechanism of its beneficial effects remains unclear. It is hypothesized that Co indirectly influences plant metabolism at low concentrations, potentially through interactions with other elements. Furthermore, Co may inhibit the production of ethylene, a hormone involved in various plant processes such as germination, growth, ripening, senescence, and stress resistance. This inhibitory effect is believed to occur through the inhibition of ACC oxidase activity in the ethylene biosynthetic pathway (Zhang et al., 2021). The plants treated with cobalt exhibited a significant increase in N, P, K, Ca, and Mg concentrations compared to the control. These findings are consistent with previous research, who observed enhanced nutrient uptake in pea with cobalt application (Gad, 2006). The beneficial influence of cobalt can be attributed to its role in stimulating hormonal synthesis (auxin and gibberellin), metabolic activity, and enzyme function (peroxidase and catalase), ultimately leading to increased growth, yield, and mineral uptake (Akeel and Jahan, 2020). Also, cobalt application enhances the formation of leghaemoglobin, a crucial protein for nitrogen fixation, leading to improved nodule activity (Gad et al., 2022). As noted, the beneficial effects of cobalt on nodulation may be attributed to its role in specific cobalamine-dependent enzyme systems within rhizobia, such as ribonucleotide reductase and methylmalonyl-coenzyme a mutase (Osman et al., 2021).

The successful integration of arbuscular mycorrhizal fungi (AMF) with selenium (Se) biofortification of snap beans in our study significantly influenced various parameters, including vegetative parameter, nutrient uptake

(N, P, K, Ca, Mg), pod production, yield, total carbohydrate content, and trace element (Se, Co) accumulation compared to the control across both growing seasons. Beneficial rhizosphere bacteria can enhance the phytoavailability of selenium by reducing oxidized and methylated forms of the element and expanding the soil volume accessible to plant roots. This may improve the efficiency of selenium-specific fertilizers. Introducing beneficial bacteria to the soil or inoculating plants with plant growth-promoting bacteria (PGPB) could potentially enhance the biofortification of crops with selenium. Additionally, plants known as selenium hyperaccumulators, which are used for the remediation of selenium-rich soils, can also serve as sources of selenium for both soil and livestock due to their high selenium content, particularly in organic forms such as SeMet and MetSeCys (Bañuelos et al., 2017).

Most plants exhibit a strong symbiotic relationship with AMF, which can enhance mineral nutrition (particularly N, P, and K), water accessibility, and stress resistance due to the substantial expansion of the root surface area through fungal hyphae. Previous research suggests that AMF can also positively impact microelement accumulation and improve plant antioxidant status (Golubkina et al., 2020). In this context, particular attention has been given to the enhancement of Se accumulation. It is hypothesized that the observed phenomenon is related to the fact that sulfate and phosphate transporters are encoded by the AMF genome leading to increased accumulation of sulfur, phosphorus, and Se. Selenates are absorbed through sulfate transporters, while selenites are taken up through phosphate transporters.

Studies have demonstrated that arbuscular mycorrhizal fungi (AMF) can significantly enhance the bioavailability and accumulation of selenium to enhance yield of plants. The combined application of AMF and selenium resulted in increased yield and quality of chickpea seeds, highlighting the synergistic effects of these two factors on plant growth and nutrient composition (Golubkina et al., 2020). Similarly, the inoculation of garlic and onion with AMF in conjunction with selenium application has been shown to increase bulb yield and enhance the antioxidant properties of these crops, suggesting that AMF can facilitate the uptake of selenium while improving overall plant health (Golubkina et al., 2020). Furthermore, the interaction between selenium application and AMF inoculation positively influenced the growth and micronutrient content of soybean plants, emphasizing the potential of AMF in biofortifying crops grown in tropical soils (Bamberg et al., 2019). In addition to selenium, the biofortification of cobalt in conjunction with mycorrhizal inoculation has also been investigated. This is particularly important as cobalt can be toxic at high concentrations, and the presence of AMF can help regulate its absorption, leading to healthier plants. Moreover, Meftah et al. (2016) demonstrated that cobalt application, when combined with mycorrhizal inoculation, positively affected the growth and nutrient content of barley and clover, indicating that AMF can play a crucial role in managing cobalt levels in crops.

Conclusion

AMF can significantly promote the growth of snap bean. Furthermore, AMF can form a mutually beneficial symbiotic relationship and promote the absorption and transport of Se and Co in snap bean crop. Additionally, the application of AMF combined with Se or Co is more effective at promoting these effects than that of Se or Co alone. Overall, AMF can be used as a bioenhancer to produce foods enriched in Se or Co during the production of crops.

Author contributions

A.A.A.O: conceptualization, methodology, field sampling, analysis and writing. A.A.M, S.A.A. and S.M.S.Y.: conceptualization, methodology, writing and revision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare no conflict of interest.

TABLE 1. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on some vegetative growth parameters of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons.

Treatments		Plant length (cm)		Number of branches/plant		Number of leaves/plant		Leaf area (cm^2)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Mycorrhizal inoculation									
Without mycorrhizae		51.20b	54.69a	2.88b	3.26a	14.44a	16.78b	149.10b	142.70b
With mycorrhizae		54.38a	55.09a	3.11a	3.48a	14.52a	17.68a	161.35a	150.24a
Foliar application of selenium or cobalt									
Control		49.11d	52.13d	2.58c	3.03d	12.45e	15.70c	130.52d	131.46d
Se 5 µM		51.22cd	52.93cd	2.89b	3.23cd	14.50bc	15.98c	138.92c	142.33c
Se 10 µM		53.34bc	54.50b	2.97b	3.39abc	14.97b	17.35b	160.16b	143.83bc
Se 15 µM		54.80ab	57.23a	3.07b	3.60a	16.38a	19.37a	175.80a	156.66a
Co 100 µM		56.53a	57.70a	3.41a	3.57a	15.88a	18.80a	179.23a	155.46a
Co 200 µM		52.58bc	55.43b	3.09b	3.50ab	14.03cd	17.30b	164.05b	148.07b
Co 300 µM		51.93cd	54.28bc	2.95b	3.27bcd	13.17de	16.10c	137.91cd	147.49bc
Mycorrhizal inoculation x foliar application of selenium or cobalt interactions									
Without mycorrhizae	**Control**	47.80d	51.67f	2.53f	2.93e	12.30e	14.73f	123.57h	128.78e
	Se 5 µM	50.71cd	52.27f	2.78def	3.13de	14.23cd	15.17ef	135.34fg	133.65e
	Se 10 µM	50.13cd	53.93def	2.87def	3.27cde	14.73c	17.27c	157.02cd	133.87e
	Se 15 µM	51.47cd	57.67ab	2.83def	3.40bcd	16.40ab	18.33bc	179.41a	148.99bcd
	Co 100 µM	56.40ab	56.60abc	3.40a	3.47abcd	15.10bc	18.00c	174.17ab	153.53bc
	Co 200 µM	51.28cd	55.73bcd	2.92cde	3.47abcd	14.92c	17.07c	146.38def	149.79cd
	Co 300 µM	50.58cd	54.93cde	2.83def	3.13de	13.40de	16.87cd	127.80gh	150.33d
With mycorrhizae	**Control**	50.42cd	52.60ef	2.63ef	3.13de	12.60e	16.67cde	137.46efg	134.14e
	Se 5 µM	51.73cd	53.60def	3.00bcd	3.33bcd	14.77c	16.80cd	142.49ef	151.00bcd
	Se 10 µM	56.55ab	55.07cd	3.07abcd	3.52abcd	15.20bc	17.43c	163.30bc	153.80bc
	Se 15 µM	58.13a	56.80abc	3.30ab	3.80a	16.35ab	20.40a	172.19ab	164.33a
	Co 100 µM	56.67ab	58.80a	3.42a	3.67ab	16.67a	19.60ab	184.28a	157.38ab
	Co 200 µM	53.88abc	55.13cd	3.27abc	3.53abc	13.13de	17.53c	181.71a	146.35bcd
	Co 300 µM	53.27bc	53.63def	3.07abcd	3.40bcd	12.93de	15.33def	148.03de	144.65bcd

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

TABLE 2. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on plant fresh and dry weights and SPAD readings of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons.

Treatments		Plant fresh weight (g)		Plant dry weight (g)		SPAD readings	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
				Mycorrhizal inoculation			
Without mycorrhizae		60.84b	79.95b	15.50b	20.58b	40.50a	37.25a
With mycorrhizae		70.00a	93.14a	18.62a	25.39a	40.65a	37.68a
				Foliar application of selenium or cobalt			
Control		58.00d	70.17c	15.01c	19.13c	40.50a	37.48a
Se 5 µM		66.67bc	84.33b	16.18bc	22.54b	40.57a	37.87a
Se 10 µM		68.63ab	97.17a	19.03a	27.54a	40.36a	38.17a
Se 15 µM		60.83cd	81.17b	16.17bc	21.85b	40.69a	37.50a
Co 100 µM		73.50a	98.00a	19.58a	26.78a	40.62a	36.36a
Co 200 µM		67.82ab	93.17a	18.08ab	23.37b	40.89a	37.70a
Co 300 µM		62.50bcd	81.83b	15.36c	19.66c	40.43a	37.14a
				Mycorrhizal inoculation x foliar application of selenium or cobalt interactions			
Without mycorrhizae	**Control**	56.67gh	63.67f	14.08d	17.11g	40.37a	37.28a
	Se 5 µM	62.33d-h	84.67cd	14.76cd	21.91de	40.53a	38.51a
	Se 10 µM	59.92fgh	90.00bc	17.09bcd	27.11ab	39.91a	39.35a
	Se 15 µM	54.33h	67.67ef	14.34d	17.45g	40.51a	35.74a
	Co 100 µM	71.33a-d	91.67bc	18.48ab	23.98cd	40.91a	36.07a
	Co 200 µM	61.30e-h	85.33cd	15.01bcd	19.14fg	40.84a	37.71a
	Co 300 µM	60.00fgh	76.67de	14.75cd	17.35g	40.42a	36.05a
With mycorrhizae	**Control**	59.33fgh	76.67de	15.94bcd	21.15ef	40.63a	37.69a
	Se 5 µM	71.00a-e	84.00cd	17.60a-d	23.17de	40.60a	37.23a
	Se 10 µM	77.33a	104.33a	20.97a	27.97ab	40.80a	36.99a
	Se 15 µM	67.33b-f	94.67abc	18.01abc	26.26bc	40.86a	39.27a
	Co 100 µM	75.67ab	104.33a	20.68a	29.59a	40.33a	36.64a
	Co 200 µM	74.33abc	101.00ab	21.15a	27.60ab	40.93a	37.69a
	Co 300 µM	65.00c-g	87.00cd	15.97bcd	21.97de	40.43a	38.23a

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

TABLE 3. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on some leaf nutrients of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons.

Treatments		Nitrogen (%)		Phosphorus (%)		Potassium (%)		Calcium (%)		Magnesium (%)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Mycorrhizal inoculation											
Without mycorrhizae		2.62b	2.71b	0.48b	0.30b	2.51b	2.61b	1.14b	1.18b	0.33b	0.41b
With mycorrhizae		2.71a	2.90a	0.51a	0.35a	2.68a	2.72a	1.34a	1.53a	0.38a	0.43a
Foliar application of selenium or cobalt											
Control		2.61c	2.63c	0.46d	0.26c	2.45d	2.49c	1.10d	1.19d	0.30c	0.39c
Se 5 µM		2.65bc	2.80ab	0.51abc	0.32b	2.49cd	2.62bc	1.23c	1.34bc	0.32c	0.42b
Se 10 µM		2.70ab	2.80ab	0.53a	0.35ab	2.68ab	2.73ab	1.33b	1.45ab	0.36abc	0.43ab
Se 15 µM		2.61c	2.77b	0.48cd	0.32b	2.59bcd	2.64bc	1.20c	1.29cd	0.34bc	0.40c
Co 100 µM		2.76a	2.91a	0.51abc	0.34ab	2.80a	2.80a	1.50a	1.46a	0.42a	0.45a
Co 200 µM		2.71ab	2.89ab	0.52ab	0.36a	2.64bc	2.71ab	1.23c	1.41ab	0.40ab	0.43ab
Co 300 µM		2.64bc	2.81ab	0.48bcd	0.32b	2.51cd	2.67ab	1.10d	1.33bc	0.32c	0.41bc
Mycorrhizal inoculation x foliar application of selenium or cobalt interactions											
Without mycorrhizae	**Control**	2.58c	2.58e	0.44e	0.21e	2.40de	2.39d	1.01g	1.08f	0.28c	0.38e
	Se 5 µM	2.65c	2.75bcde	0.52bc	0.31cd	2.38e	2.61bcd	1.08fg	1.20ef	0.31bc	0.41bcd
	Se 10 µM	2.62c	2.72cde	0.49bcde	0.32abcd	2.71bc	2.75abc	1.20de	1.26def	0.33bc	0.42bc
	Se 15 µM	2.59c	2.60e	0.48cde	0.28d	2.56bcde	2.62bcd	1.14def	1.17ef	0.33bc	0.38de
	Co 100 µM	2.68bc	2.82abcd	0.49bcde	0.32abcd	2.57bcde	2.69abc	1.43b	1.27def	0.37abc	0.43abc
	Co 200 µM	2.63c	2.77bcde	0.49bcde	0.35abc	2.49cde	2.57cd	1.10efg	1.18ef	0.38abc	0.42bc
	Co 300 µM	2.59c	2.70de	0.46de	0.31bcd	2.47cde	2.68abc	0.99g	1.08f	0.28c	0.40cde
With mycorrhizae	**Control**	2.63c	2.69de	0.48cde	0.32bcd	2.50cde	2.60cd	1.18def	1.29de	0.32bc	0.40bcde
	Se 5 µM	2.66c	2.84abcd	0.49bcde	0.34abcd	2.61bcde	2.64bcd	1.38b	1.47bc	0.33bc	0.44abc
	Se 10 µM	2.79ab	2.89abcd	0.58a	0.38a	2.65bcd	2.72abc	1.46ab	1.63ab	0.39ab	0.44ab
	Se 15 µM	2.62c	2.94ab	0.47cde	0.35abc	2.63bcd	2.66abc	1.25cd	1.41cd	0.36abc	0.42bcd
	Co 100 µM	2.83a	3.00a	0.53abc	0.37ab	3.03a	2.91a	1.56a	1.66a	0.46a	0.46a
	Co 200 µM	2.78ab	3.01a	0.54ab	0.38a	2.79b	2.86ab	1.35bc	1.63ab	0.41ab	0.44ab
	Co 300 µM	2.69bc	2.92abc	0.51bcd	0.33abcd	2.55bcde	2.66abc	1.20de	1.58ab	0.36abc	0.42bcd

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

TABLE 4. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on number of pods/ plant and plant yield of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons.

Treatments		Number of pods/plant		Plant yield (g)	
		1st season	2nd season	1st season	2nd season
Mycorrhizal inoculation					
Without mycorrhizae		23.33b	22.71b	122.38b	112.77b
With mycorrhizae		25.57a	25.33a	132.03a	118.01a
Foliar application of selenium or cobalt					
Control		20.00e	20.83d	110.91c	109.70d
Se 5 µM		24.00cd	23.67bc	114.24c	111.52cd
Se 10 µM		26.17ab	25.33a	135.45ab	118.64a
Se 15 µM		25.00bc	24.83ab	134.24ab	116.97abc
Co 100 µM		27.17a	25.50a	138.03a	120.30a
Co 200 µM		26.00ab	24.83ab	134.85ab	118.03ab
Co 300 µM		22.83d	23.17c	122.73bc	112.58bcd
Mycorrhizal inoculation x foliar application of selenium or cobalt interactions					
Without mycorrhizae	**Control**	18.67g	19.33e	107.58d	107.27e
	Se 5 µM	22.33ef	21.67d	110.91cd	110.00de
	Se 10 µM	25.00cd	24.33abc	130.61abc	115.76abcde
	Se 15 µM	24.67d	23.67bcd	130.91abc	113.03bcde
	Co 100 µM	25.67bcd	24.67ab	131.82abc	117.58abcd
	Co 200 µM	25.00cd	23.67bcd	131.52abc	114.24bcde
	Co 300 µM	22.00ef	21.67d	113.33cd	111.52de
With mycorrhizae	**Control**	21.33f	22.33cd	114.24cd	112.12cde
	Se 5 µM	25.67bcd	25.67ab	117.58bcd	113.03bcde
	Se 10 µM	27.33ab	26.33a	140.30a	121.52ab
	Se 15 µM	25.33bcd	26.00a	137.58ab	120.91abc
	Co 100 µM	28.67a	26.33a	144.24a	123.03a
	Co 200 µM	27.00abc	26.00a	138.18ab	121.82ab
	Co 300 µM	23.67de	24.67ab	132.12abc	113.64bcde

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

TABLE 5. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on pod total carbohydrates and fibres of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons

Treatments		Total carbohydrates (g/100 g D.W)		Fibres (%)	
		1st season	2nd season	1st season	2nd season
		Mycorrhizal inoculation			
Without mycorrhizae		20.22b	20.03b	12.57a	15.11a
With mycorrhizae		21.11a	21.94a	13.45a	15.71a
		Foliar application of selenium or cobalt			
Control		16.88d	16.84d	13.05a	14.91a
Se 5 µM		20.12c	20.11bc	12.51a	15.89a
Se 10 µM		22.24ab	23.09a	13.52a	15.39a
Se 15 µM		20.77bc	22.81a	13.43a	14.71a
Co 100 µM		22.75a	24.24a	12.86a	15.70a
Co 200 µM		22.06ab	21.10b	13.10a	15.25a
Co 300 µM		19.84c	18.68c	12.62a	16.02a
		Mycorrhizal inoculation x foliar application of selenium or cobalt interactions			
Without mycorrhizae	**Control**	16.86d	15.87h	12.50a	16.05a
	Se 5 µM	19.32c	18.64efg	12.62a	15.25a
	Se 10 µM	22.00ab	22.37bcd	14.02a	14.90a
	Se 15 µM	20.63bc	22.21bcd	12.40a	13.95a
	Co 100 µM	22.20ab	23.01bc	12.07a	15.10a
	Co 200 µM	21.72ab	20.63cde	12.63a	14.27a
	Co 300 µM	18.78cd	17.45gh	11.75a	16.27a
With mycorrhizae	**Control**	16.89d	17.82fgh	13.60a	13.77a
	Se 5 µM	20.91abc	21.58bcd	12.40a	16.53a
	Se 10 µM	22.47ab	23.80ab	13.02a	15.88a
	Se 15 µM	20.91abc	23.40ab	14.46a	15.47a
	Co 100 µM	23.30a	25.47a	13.65a	16.31a
	Co 200 µM	22.40ab	21.58bcd	13.57a	16.23a
	Co 300 µM	20.90abc	19.91def	13.48a	15.77a

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

TABLE 6. Effect of mycorrhizal inoculation and foliar spraying of selenium or cobalt on selenium and cobalt contents in pods of snap bean cv. Paulista in 2020/2021 and 2021/2022 growing seasons.

Treatments		Se content in pods (mg/kg)		Co content in pods (mg/kg)	
		1st season	2nd season	1st season	2nd season
Mycorrhizal inoculation					
Without mycorrhizae		0.254b	0.288b	2.061b	1.990b
With mycorrhizae		0.327a	0.318a	2.280a	2.225a
Foliar application of selenium or cobalt					
Control		0.196b	0.196d	1.328c	1.465d
Se 5 µM		0.372a	0.350b	1.623c	1.432d
Se 10 µM		0.390a	0.407a	1.583c	1.512d
Se 15 µM		0.425a	0.436a	1.598c	1.612d
Co 100 µM		0.220b	0.250c	2.683b	2.430c
Co 200 µM		0.223b	0.255c	2.987b	2.903b
Co 300 µM		0.208b	0.229cd	3.392a	3.397a
Mycorrhizal inoculation x foliar application of selenium or cobalt interactions					
Without mycorrhizae	**Control**	0.150e	0.197fg	1.250d	1.417c
	Se 5 µM	0.343abcd	0.336d	1.653d	1.347c
	Se 10 µM	0.357abc	0.390bc	1.500d	1.393c
	Se 15 µM	0.380abc	0.429ab	1.517d	1.557c
	Co 100 µM	0.197de	0.242ef	2.520c	2.160d
	Co 200 µM	0.187e	0.237efg	2.823bc	2.703c
	Co 300 µM	0.163e	0.187g	3.167ab	3.350ab
With mycorrhizae	**Control**	0.241cde	0.195fg	1.407d	1.513c
	Se 5 µM	0.400ab	0.363cd	1.593d	1.517c
	Se 10 µM	0.423a	0.423ab	1.667d	1.630c
	Se 15 µM	0.470a	0.444a	1.680d	1.667c
	Co 100 µM	0.243cde	0.257e	2.847bc	2.700c
	Co 200 µM	0.260bcde	0.273e	3.150ab	3.103b
	Co 300 µM	0.252cde	0.271e	3.617a	3.443a

Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

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فطريات الميكوريزا الحويصلية تحسن من التعزيز الحيوي للسيلينيوم والكوبلت في الفاصوليا

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الملخص

بالرغم من أن عنصري السيلينيوم والكوبلت من العناصر النادرة الهامة التي يحتاجها الانسان، الا أن حصول الإنسان عليهما من الغذاء يكون بكميات غير كافية في العالم. وبالتالي فإن التعزيز الحيوي للسيلينيوم والكوبلت هو طريقة شائعة لزيادة امتصاص العنصرين والحفاظ على صحة الإنسان. إن العدوي بفطريات الميكوريزا الحويصلية للنباتات له العديد من الأدوار الهامة في تحسين امتصاص النبات للعناصر، النمو، المحصول ومقاومة الاجهادات البيئية. هذه الأدوار يمكن توظيفها في التعزيز الحيوي بالسيلينيوم والكوبلت في الفاصوليا وتحسين النمو والمحصول. أجريت تجربة حقلية خلال موسمي 2021/2020 و2022/2021 بمزرعة الخضر، قسم البساتين، كلية الزراعة، جامعة عين شمس، محافظة القليوبية، مصر. أجريت التجربة لدراسة تأثيرات الرش الورقي بالسيلينيوم والكوبلت والعدوى بفطريات الميكوريزا الحويصلية على نمو ومحصول وجودة نباتات الفاصوليا النامية بتربة طينية. أظهرت النتائج ان التفاعل بين الميكوريزا والرش الورقي بالسيلينيوم بتركيز 10 ميكرومولار أو الكوبلت بتركيز 100 ميكرومولار أدى لتحسينات في قراءات النمو الخضري، قراءة درجة اخضرار الأوراق، محتوى العناصر، والقراءات المحصولية وكما أدى إلى إنتاج قرون فاصوليا معززة حيوياً بعنصري السيلينيوم والكوبلت في كلا الموسمين. وكاستنتاج، يمكن استخدام فطريات الميكوريزا الحويصلية لتحسين التعزيز الحيوي للسيلينيوم والكوبلت خلال زراعة وإنتاج الفاصوليا.

الكلمات الدالة: *Phaseolus vulgaris* L. ، السيلينيوم ، الكوبلت ، التعزيز الحيوي، فطريات الميكوريزا الحويصلية.