OPTIMIZING BEAN CULTIVATION: MYCORRHIZAL APPLICATIONS AND MITIGATING PHYTOPATHOLOGICAL CHALLENGES IN SUSTAINABLE AGRICULTURE

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Abstract. Of the 60 million tons of legumes produced globally, beans account for 17,662,028. Turkey ranks third among the producers of green beans worldwide, with an annual production of 587, 967. Bean rust disease (*Uromyces appendiculatus*), root rot disease (*Rhizoctonia solani*), and bean common mosaic disease (Bean common mosaic potyvirus) are the primary afflictions affecting bean crops in the Aegean Region. Diseases can result in significant crop loss and reduced seed quality. Therefore, it is crucial to carry out pest control activities using sustainable agricultural techniques to minimize the impacts on human and environmental health, agroecosystems, and biological balance. This study aimed to establish mycorrhiza applications in beans as a sustainable approach for plant protection activities, providing more profitable production advantage by reducing fungicide use when combined within the framework of integrated disease management. Based on these findings, mycorrhiza application reduced rust infection by 40% and BCMV infection by 30.2% in the sensitive genotypes. Our field experiments demonstrated that the application of mycorrhiza resulted in 34% reduction of rust disease outbreaks and 65% less use of fungicides compared to the untreated plants.
Keywords: *mycorrhiza, soilless agriculture, common bean, virus, inactivation*

Introduction

Recently, there has been a surge in the cultivation of legumes, which play a vital role in human nourishment. Beans, among other legumes, hold tremendous importance as they are in high demand by consumers as key ingredients in their meals. Among legumes, beans are the most discerning species in terms of ecological conditions. There are numerous ecological factors, including precipitation, temperature, day length, topography, and soil type, which can significantly affect yield. Furthermore, biological factors, such as pests and diseases, as well as socioeconomic factors, can also play a significant role (Uebersax et al., 2023). Beans are conventionally grown in open fields during two distinct periods of the year, usually spring and autumn. Alternatively, they can be grown under cover in autumn and winter to ensure year-round supply for consumers. Beans are one of the most commonly cultivated grain legumes for food, ranking second in terms of global cultivation area, after lentils (Xiong et al., 2023). In 2022, the FAO reported that 36 million hectares are dedicated to global dry bean cultivation, whereas fresh beans occupy an area of 1.5 million hectares. Dry bean production amounts to 31 million tons, while fresh beans produce 24 million tons. For dry beans, the yield was 8,614 kg/ha, whereas fresh beans yielded 153,302 kg/ha. Bean Rust Disease, caused by *Uromyces appendiculatus var. appendiculatus* (Pers.:Pers.) Unger is a prevalent disease that significantly affects bean production worldwide. Significant epidemics can occur, particularly in tropical and subtropical areas of America and Africa. It also causes significant losses in many regions of Turkey, which has a temperate climate.

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U. appendiculatus isolates with high virulence have been reported in several geographic regions (Mmbaga and Stavely, 1988; Stavely et al., 1989; Mmbaga et al., 1996; Jochua et al., 2008). Although numerous isolates exhibit a large variety of virulence patterns, *U. Appendiculatus* has been categorized into two main pathotype groups (Mmbaga et al., 1996; Araya et al., 2004). *U. appendiculatus*, an obligatory parasite, completes all stages of its life cycle within a single host, and does not require an alternate host. Uredospores, the summer spores, develop on the upper surface of leaves and appear as brownish-red pustules. Teliospores, which are durable spores, are typically dark brown to black in hue and do not typically form an esyum. Uredospores, which are the primary source of infection, are single-celled and have thin walls. If environmental conditions are favorable, they rapidly germinate and penetrate plant tissues (Park et al., 2003).

Root rot, caused by the pathogen *Rhizoctonia solani* Kühn, is a highly significant disease that affects beans in humid and tropical regions. Godoy-Lutz et al. (2008) and Montoya et al. (1997) also reported on the severity of the disease in beans. Owing to its facultative parasitic nature, the pathogen can persist in the soil as a saprophyte for several years (Zhao et al., 2005). *R. solani* is capable of causing the death of bean plants during the seedling stage, as well as inducing root or hypocotyl rot and stem cankers. The initial symptoms manifest as reddish-brown soft lesions or cankers that appear in a linear or circular pattern on the roots or hypocotyls. The fungus then infiltrates the lower part of the stem, thereby fostering brown rot. The plant can ultimately expire owing to severe infections. As the season nears its end, mixed infections of Fusarium and Pythium species in the soil may also occur. Symptoms resulting from Rhizoctonia infection can also be detected on capsules exposed to damp soil surfaces. Pathogens can lead to the decay of these capsules (Chet and Baker, 1981).

Genetic resistance is the most effective strategy for managing root rot disease (Schwartz et al., 2005). Unfortunately, no commercially available resistant varieties have been cultivated. Hence, disease control is commonly achieved through the application of chemical fungicides to leaves and seeds (Tian et al., 2021; Diagne et al., 2020).

Effects of arbuscular mycorrhizal fungi on plant health and development

Plants have established mutualistic relationships with specific soil fungi, namely arbuscular mycorrhiza (AM), for over 400 million years. More than 80% of terrestrial plants, including gricultural crops and forest trees, form this beneficial relationship (Newman and Reddell, 1987; Wang and Qui, 2006; Dhalaria et al., 2020; Song et al., 2020). Arbuscular mycorrhizae (AMF) are fungi belonging to the phylum Glomeromycota. This phylum is divided into four subgroups, with approximately 150-200 different fungi being identified (Schüssler et al., 2001). Arbuscular mycorrhizae are obligate biotrophs that require host plants to complete their life cycle. Upon colonization of the root cortex, the fungus forms arbuscules, specialized structures which regulate the exchange of mineral materials. Extracellular hyphal networks spread throughout the soil and facilitate the uptake of mineral nutrients from the deeper layers (Smith et al., 2011; Yu et al., 2022; Marro et al., 2022). The plant, in turn, provides photosynthetic products that the mycorrhiza utilize in this symbiotic relationship (Smith and Smith, 2011). Plants experience substantial alterations in their primary and secondary metabolic processes, in addition to activating defense mechanisms while regulating the mycorrhizal relationship (Harrison, 2005; Hause and Fester, 2005; Khan et al., 2022; Boutaj et al., 2022). These changes frequently cause significant modifications in the

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physiology of plants, enabling them to effectively manage both biotic and abiotic stressors.

Fungal, bacterial, and viral diseases pose significant challenges to bean cultivation. These challenges are among the limiting factors faced by farmers during bean cultivation. Bean anthracnose, which results in dark red-brown lesions on leaves and veins; bean root rot disease caused by *Fusarium spp.*, *Rhizoctonia solani*, and *Macrophomina phaseolina*, leading to root decay; and bean rust disease, which causes brown lesions with open yellow edges on plant leaves and fruits, are considered crucial fungal diseases for bean crops. Objective evaluation of these diseases is essential for the development of effective countermeasures. The technical abbreviations should be explained promptly. Common academic sections and precise word choices should be employed while avoiding biased, figurative, or ornamental languages. The language should be kept formal, while ensuring grammatical correctness and consistency in style and format. Bacterial diseases, including the common bacterial blight of beans (*Xanthomonas axonopodis pv. phaseoli*) and halo blight (*Pseudomonas savastanoi pv. phaseolicola*), as well as viral pathogens such as bean common mosaic potyvirus (BCMV) and bean yellow mosaic potyvirus (BYMV), can result in significant losses in bean crops. These pathogens have the potential to cause substantial damage, especially under favorable climatic conditions (Liang et al., 2022).

The increasing demand for dependable food sources has prompted researchers to explore safer and healthier approaches for disease control, ultimately decreasing the need for chemical treatments. It is widely recognized that the mutually advantageous relationship between beneficial soil microorganisms, such as mycorrhizal fungi and plants, encourages plant growth and helps plants cope with abiotic and biotic environmental stressors. Physiological changes that occur in the host plant during mycorrhizal colonization affect multiple microorganisms that interact with the plant's root and aboveground systems. Various plant species, including crop plants, have demonstrated the protective effects of mycorrhizal symbiosis against pathogens. During colonization, biochemical communication occurs between the plant and mycorrhiza. This results in the activation of local and systemic defence systems in the plant, enabling more effective responses to potential biotic stress factors and maintaining the plant in a prepared state. The discovery of this effect of mycorrhiza and its high potential increases the possibility of its use as an alternative method for plant protection.

This study investigated the impact of mycorrhizae on bean ailments, such as rust, root rot, and common bean mosaic diseases. These diseases are particularly significant in terms of their effects on bean crops.

Materials and Methods

In this study, three distinct pathogenic agents were tested in this study. These microbes were obtained from bean plots grown in the experimental fields of the Faculty of Agriculture, Department of Plant Protection, and Department of Horticulture, Ege University. The pathogens responsible for the diseases studied here in are Bean common mosaic virus (BCMV) that causes common bean mosaic disease, *Uromyces appendiculatus* (Pers.) C. K. causes rust disease, and *Rhizoctonia solani* causes root rot. A total of 170 distinct bean populations were gathered from various regions across Turkey, mainly the Aegean and Marmara areas, and from producers and researchers upon request. Technical abbreviations are explained based on their first usage. Spelling and grammar were aligned with the British English conventions. Seeds from these populations

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were sown, and their morphological and agronomic traits were evaluated. The language is objective and formal and lacks filler words. The text adheres to the conventional academic structure and features a clear progression and causal connections between statements. The register is impartial, without biased language or emotional connotations. Genotypes sensitive to rust and BCMV, based on cultivation and observations, were selected for this study which are *Vigna unguiculata*, *Phaseolus vulgaris* and *Phaseolus lunatus*. This study utilized a commercial mycorrhiza preparation. Species of mycorrhiza that were composed are;

Glomus intraradices,
G. mosseae,
G. aggregatum,
G. clarum,
G. monosporum,
G. deserticola,
G. brasilianum,
G. etunicatum,
Gigaspora margarita.

A commercially available fungicide with a WP formulation containing 80% mancozeb active substance was used to control the rust pathogen, and a commercial fungicide with a WP formulation containing 80% thiram active substance was used to control the root rot pathogen. Applied devices during this study are;

Sartorius GP3202-0CE Scale
Hirayama HV-50L Autoclav
Sanyo MIR-154
Tarsons Racked Graduated Filter Tips
Eppendorf Research Plus Adjustable Micropipettes
BioTek Instruments ELx800 Universal Microplate Reader
Varian Cary 100 Bio UV-Visible Spectrophotometer

To ensure balance in sample size across groups over time and to have high accuracy level randomized block design statistical methodology were used during this study.

Mycorrhiza applications

Mycorrhiza applications were conducted through seed coating. Prior to coating, the seeds were soaked in a 3% solution of sodium hypochlorite (NaOCl) for 3 min and rinsed with sterile distilled water three times. The applications were made with a commercial mycorrhizal mixture, and the recommended dosage of 250 g of preparation was applied per 200-250 g of seeds.

Plant cultivation for mycorrhizal trials

To compare the effects of mycorrhizal seed coating on these pathogens, pot trials were conducted. Following coating, dry seeds were planted in pots containing a mixture of peat, coir, and perlite in a 3:2:1 ratio. The growth material was sterilized by autoclaving to avoid possible contamination. The plants were grown in climate-controlled rooms at a temperature of 23±1°C and relative humidity of 65-75%, with a light intensity of 300 µmol photon m -2 S -1 provided for a 16/8 h light/dark cycle.

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Pathogen inoculation

The process of inoculating BCMV was carried out by grinding the first, BCMV-infected leaves in a sterile mortar with 1 g of leaves in 10 ml of phosphate buffer (1% K_2HPO_4, 0.1% Na_2SO_3, pH7.5) when the primary leaves of the plants were between 1/2 and 3/4 in size, following the methodology described by Sengooba et al. (1997) and Deligoz and Sokmen (2013). Carborundum powder was sprinkled onto the leaves, and the virus was transferred to the plants using single-use plastic gloves. The inoculated leaves were washed with tap water. To ensure adequate rust inoculation, single pustule isolates were obtained using a susceptible variety under controlled conditions (*Figures 1A and 1B*). Plants were cultivated in a greenhouse with 20 °C of temperature and inoculation was performed when the first leaves were completely grown. To initiate inoculation, a suspension of spores was prepared containing 2 × 104 uredospores/ml. Application dose of the inoculum were 15,800 propagule/daa. The leaves were sprayed using a hand sprayer, as shown in *Figure 1D*. Subsequently, the plants were covered with cellophane for one day, creating favorable penetration conditions, as shown in *Figure 1E*. The temperature in the climate chamber was maintained at 18±2°C during the first day of inoculation and the plants were kept in the dark for 24 h. After 24 h, the plants were returned to standard conditions for growth, as per Altikardesler and Arslan (2007).

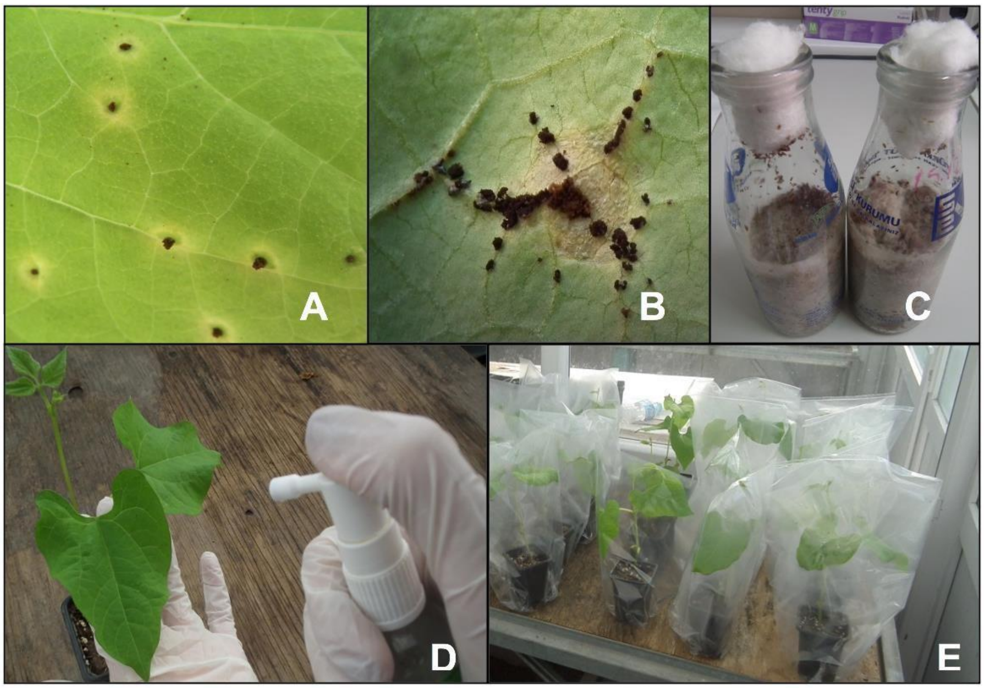

Figure 1. *Images depicting the inoculation stages (Four Biological Replications)*

Rhizoctonia solani was primarily grown on PDA medium, followed by mass production of mycelial plugs using sterilized sand-vermiculite medium (*Figure 1C*). To prepare the medium, 150 g of wheat bran was placed in appropriate glass containers and 15 ml of water was added. The containers were autoclaved at 121°C for 30 min, followed by cooling. During this period, the mycelial mass culture of *R. solani* at the active growth stage was dissected into eight fragments using an inoculation needle. Each piece was then inoculated into a container containing bran medium and kept in the dark at 25°C for

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15 days. Subsequently, the resulting stock inoculum was blended with potting soil at a ratio of 50:1 (Turhan, 1992; Allen, 1997).

Assessment of disease severity

The severity of the bean common mosaic virus (BCMV) infection was evaluated by examining at least 10 plants and 50 leaves. A scale was used for assessment, with the following values: 0, no mosaic symptoms, 1 three mosaic lesions, 2 six mosaic lesions; and 3, more than six mosaic lesions.

The severity of the disease caused by *Rhizoctonia solani* was determined based on the root damage rate using the scale provided by Carling et al. (1999). The scale values used were as follows: seedlings exhibited varying degrees of damage, ranging from no damage to death, with low-level color changes in the hypocotyl, color changes in the hypocotyl and necrotic lesions with a diameter of less than 1 mm, color changes in the hypocotyl and necrotic lesions with a diameter of more than 1 mm, and death of seedlings at the respective levels.

The success of mycorrhiza application against bean common mosaic virus (BCMV) was evaluated by determining the virus concentration within the true leaves via DAS-ELISA. DAS-ELISA testing was performed using antibodies specific for BCMV (Ekren et al., 2023; Paylan et al., 2018). Initially, 200 µl of IgG was added to each well of the ELISA plates, followed by a dilution of 1:1000 in coating buffer (commercial kits from Bioreba). The plates were then incubated at 37°C for four hours. Subsequently, leaf samples and positive and negative controls were added to each well at a volume of 200 µl and incubated at 4°C overnight, as prepared using the extraction buffer. Conjugated IgG diluted in conjugate buffer from Bioreba's commercial kits at a ratio of 1:1000 was added to each well at a volume of 200 µl. The mixture was incubated at 37°C for 4 h. Subsequently, the positive samples were supplemented with a substrate solution (p-nitrophenylphosphate) to acquire a yellow color. The mixture was incubated at room temperature in a volume of 200 µl. During testing, washing occurred after coating, sample loading, and conjugation. The ELISA plates were washed with wash buffer and left to stand for 3 min before repeating this process four times. Yellow color formation was observed, and the ELISA reader device was used to conduct spectrophotometric analysis at a wavelength of 405 nm to evaluate the results (Paylan et al., 2014; Atik and Paylan, 2023).

Comparison of mycorrhizal and fungicide efficacy under field conditions

The potential use of mycorrhizal applications in the management of rust and root rot disease was evaluated under field conditions. Seeds were coated with mycorrhizae and planted in the field. After emergence, one group of plants was not treated with mycorrhizae, whereas the other group received a fungicide treatment containing 80% mancozeb and 80% thiram from the onset of rust symptoms.

Disease severity was scored on the above scales for plants without mycorrhiza treated with fungicide, and for plants with mycorrhiza treated without fungicide. Mychorrhiza and fungicide treatments were made separately in order to compare the effects of different treatment methods.

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Results

Effects of mycorrhizal application on rust disease severity

The mycorrhizal seed coating had no significant effect on the severity of rust disease in China. The disease severity was 29% in the group without mycorrhizal application and 30% in the group with mycorrhizal application (*Figure 2A*). In contrast, in genotype 55, which was considered susceptible, mycorrhizal application suppressed rust disease severity, and the difference between the groups was statistically significant. In this genotype, the disease severity was 71% in the mycorrhizal group and 42% in the non-mycorrhizal group (*Figure 2B*). Mycorrhizal application reduced disease severity by approximately 40% compared with that in the control group.

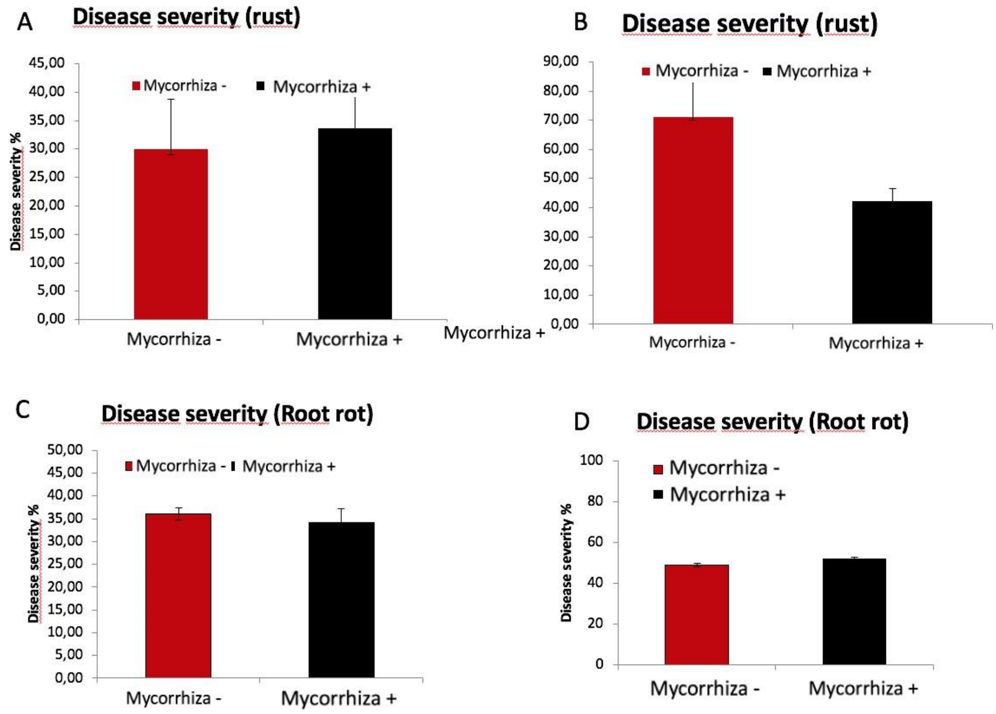

Figure 2. *Effects of Mycorrhizal Application on Disease Onset (Four Biological Replications)*

Effects of mycorrhizal application on bean root rot

Mycorrhizal application did not affect the incidence of root rot in either variety. In variety Gina, the group without mycorrhizal application had a 36% disease incidence, whereas the mycorrhizal group had a 34% disease incidence (*Figure 2C*).

As expected, the disease was more severe in genotype 34 patients. However, there was no statistically significant difference between the treatments. The disease severity was 48% in non-mycorrhizal plants and 51% in mycorrhizal plants (*Figure 2D*).

Effects of mycorrhizal application on BCMV infection

According to the results of studies conducted on bean plants mechanically inoculated with BCMV, mycorrhizal application affected BCMV colonization by 30.2% in genotype 123 and 16.6% in variety Gina (*Table 1*).

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Table 1. *Effects of Mycorrhizal Application on BCMV Infection (ELISA Results) (Four Biological Replications)*

Genotype	Application	ELISA Values		% Effect
123	Mycorrhiza + BCMV	0,484	a*	30,2
	Control + BCMV	0,694	b	---
Gina	Mycorrhiza + BCMV	0,532	a*	16,6
	Control + BCMV	0,638	b	---

Comparison of mycorrhizal and fungicidal efficacy under field conditions

In two separate open field trials, root rot was not observed to a sufficient extent for evaluation. As no disease was observed even in the untreated control plants where no application was made (0% disease incidence), no comparison could be made for this pathogen. The lack of disease incidence is thought to be related to prevailing climatic conditions and insufficient presence of the pathogen in the soil. Plants with no application showed 43% disease severity. In plants where only mycorrhizal seed coating was applied, disease severity was reduced to 28%, whereas in plants without mycorrhizal coating but with fungicide application, disease severity was recorded at 15% (*Figure 3*). According to these results, mycorrhiza application reduced disease incidence by 34% compared to plants without application, whereas fungicide application reduced disease incidence by 65%, and the differences between applications were statistically significant.

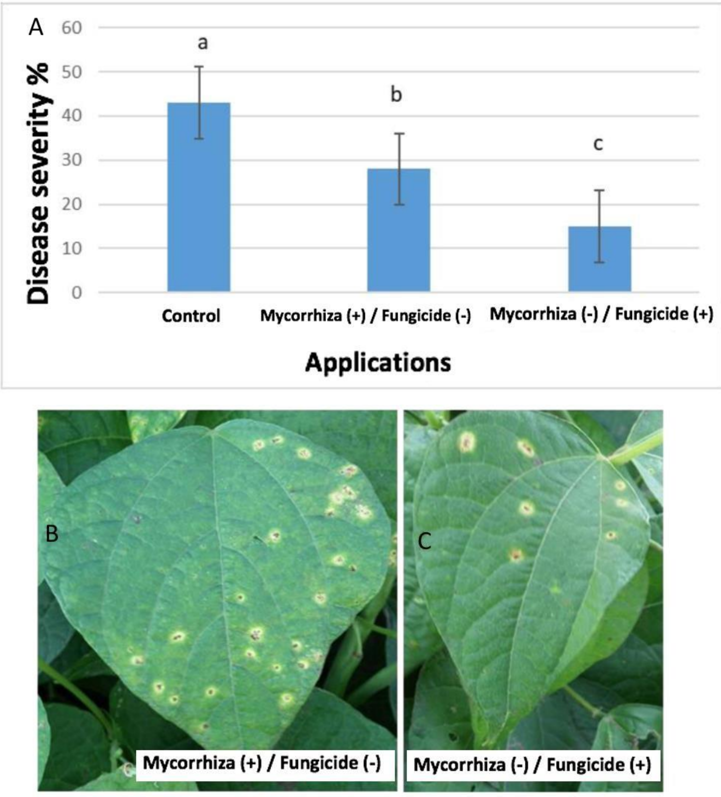

Figure 3. *Comparison of Mycorrhiza-Fungicide Efficacy in Field Conditions (Four Biological Replications)*

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Evaluation from a phytosanitary point of view

Some common problems were observed in both soilless and soil-bound cultivation, and the diseases and pests encountered varied according to the system used. In soilless systems, root and crown diseases caused by *Fusarium spp.* and *Rhizoctonia solani* were not observed, whereas in standard cultivation, these pathogens were found to infect plants and lead to their complete destruction. Considering that the same seeds were used in both systems, it is assumed that these pathogens were present in the soil, possibly maintaining their existence through durable structures (e.g., chlamydospores, sclerotia, etc.).

White mold in beans caused by *Sclerotinia sclerotiorum* was prevalent in both cropping systems. The pathogen infects leaves, stems, and fruits, affecting the whole plant, and in some cases causing wilting. The incidence of this pathogen was similar in both the production systems. Based on these observations, this pathogen was the most problematic under our growing conditions.

Powdery mildew, caused by Erysiphe species, is a major problem encountered. This powdery mildew pathogen was more prevalent in the soilless system, especially in the lower leaves.

Discussion and Conclusion

Arbuscular mycorrhizal fungi are known to generally enhance nutrient uptake in plants. However, on the other hand, these species possess many other beneficial features for plants. For instance, studies have shown that these species can confer resistance to some soil-borne pathogenic fungi when they colonize roots (Liu et al., 2023; Franczuk et al., 2023). Mycorrhizal colonization that enables plants to respond more rapidly and robustly to pathogens they encounter later is referred to as mycorrhiza-induced resistance (Lavado and Chiocchio, 2023). For example, Cordier et al. (1998) reported that the colonization of tomato roots by *Glomus mossae* led to rapid and strong activation of defense mechanisms, providing resistance against *Phytophthora parasitica*. However, the impact of mycorrhizal symbiotic relationships on leaf and root pathogens may not always be consistent or variable. Although root colonisation has been reported to induce systemic resistance against leaf pathogens (Liu et al., 2007), it is also documented in the literature that it may increase susceptibility to biotrophic pathogens (Gernns et al., 2001; Whipps, 2004). The outcomes of these reactions may vary depending on the plant and mycorrhizal species, physiological conditions, and incubation period.

There is limited literature on the effects of mycorrhizae on the control of root rot disease in beans. In this study, both controlled and field conditions were examined to determine the efficacy of mycorrhizae in controlling this disease. Better-developed plants are potentially more resistant to pathogens than weaker plants. In this context, in our study, mycorrhizal plants, despite being better developed, did not inhibit the growth of *R. solani*. This result does not align with that of Abdel- Fattah et al. (2011), who reported that AM colonization reduced the negative impact of *R. solani* on bean growth, yield, and mineral composition. Another study found that mycorrhizal colonization increased the expression of two defence-related genes (Chi and Egase) in beans and suggested that the observed resistance reactions might be associated with these genes. However, in line with our findings, it is also documented in the literature that a mycorrhizal species, *G. intraradices*, had no effect on *R. solani* (Khan et al., 2022). The diversity in interactions among mycorrhiza, pathogens, and hosts indicates that the outcome depends

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on the specificity of the host, type and density of the pathogen, environmental conditions during evolution, and mycorrhizal fungi involved in the relationship.

In this study, we investigated the effects of mycorrhizae on the development of rust disease caused by the pathogen *Uromyces appendiculatus*. According to our findings, mycorrhiza application in plants (sensitive genotype) reduced the severity of rust disease by 40% compared with control plants. It was observed that mycorrhizal seed coating, while promoting healthier plant growth compared to control groups, was not as effective as fungicide applications under field conditions. To the best of our knowledge, this is the first study to demonstrate the effectiveness of mycorrhizal species in suppressing bean rust.

Rust pathogens are obligate biotrophic fungi that require living host tissues for growth and reproduction. The urediniospores did not form epiphytic mycelia. Upon germination of urediniospores, the resulting mycelium grows towards the stomata, forms appressoria, and penetrates through the stomata. The penetrating mycelium develops within the leaf cells and produces thousands of new urediniospores.

In a separate study, the effects of mycorrhizal fungi were investigated under greenhouse conditions against another rust pathogen, *Puccinia graminis* Pers. *F. sp. tritici*. The results showed that the application of arbuscular mycorrhizal fungi significantly reduced the onset of rust disease, increased the activities of peroxidase and polyphenol oxidase enzymes, and affected the total phenol content.

It is well known that the factors influencing disease development in plants include the pathogen, host plant, and environmental conditions. The cultivation method and prevailing environmental conditions during the application of this method are important amidst these factors. In this study, we examined plant protection problems encountered under different cultivation conditions. Problems that are not commonly observed in classical cultivation methods have significantly increased in soilless cultivation. For example, gray mold caused by *Botrytis cinerea* is among the prominent issues, and these symptoms are mostly observed in the lower leaves and pods. Considering that the production environment in soilless cultivation is continuously moist and wet, it can be explained why the relative humidity is higher in this environment, making gray mold a significant issue. In addition, the architectural structures and ventilation systems of greenhouses used for cultivation are not always identical. The effects of these variables should always be considered.

Root and root collar pathogens that cause yield and quality losses pose significant challenges to bean cultivation. Pathogens, such as *Fusarium spp. and Rhizoctonia solani*, create resilient structures (sclerotia, chlamydospores, etc.) that allow them to persist in the soil for many years. These structures are often resistant to fungicides. Moreover, effectively reaching targets in soil with fungicides is generally challenging, and such applications can have undeniable negative effects on human and environmental health. In our study, we did not encounter root rot disease was not observed during soilless cultivation. However, as the results indicate, root rot caused by *Rhizoctonia solani* is among the fundamental plant protection problems in traditional soil-based cultivation. The fact that we did not encounter these pathogens in soilless cultivation can be explained by the use of cultivation materials in hydroponic systems that are free from these pathogens and their ability to disinfect the nutrient solutions used in the system. These difficult- to-control pathogens in soil are no longer a problem in hydroponic cultivation.

The increasing global population's need for adequate nutrition and the growing demand for safe food sources obtained through sustainable methods are among the most

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important factors directing plant protection strategies. Biological control methods, such as the use of beneficial microorganisms or their metabolites, are becoming increasingly important for plant protection. In recent years, studies conducted on various plants have shown that mycorrhizae strengthen plant defense systems and promote plant growth.

This study explored the potential use of mycorrhizae in the management of certain disease agents in beans, both in climate chamber conditions and in the field. Our data indicate that mycorrhizae have significant potential for controlling these diseases.

Disclosure of potential conflicts of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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