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Synergistic Effects of *Glomus mosseae* and Peatmoss on Growth Enhancement of *Raphanus sativus* and *Eruca sativa*

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ABSTRACT

This research aimed to compare the effects of the mycorrhizal fungus *Glomus mosseae* on the growth performance of *Raphanus sativus* (radish) and *Eruca sativa* (arugula) under different soil treatments. Plants were cultivated in pots containing clay soil subjected to various treatments, including peatmoss, mycorrhizal inoculation, and their combinations. Each treatment involved 20 seeds per plant species. After four weeks of cultivation, germination percentage, dry root weight, vegetative length, root system length, and fresh root weight were recorded and statistically analyzed. The highest germination rates of *Raphanus sativus* (85%) and *Eruca sativa* (75%) were obtained in the clay soil-peatmoss-mycorrhizae treatment, whereas the lowest were observed in clay soil alone (50% and 45%, respectively). The same treatment also yielded the greatest vegetative and root lengths (27 cm and 21 cm; 20.5 cm and 16.8 cm, respectively) and fresh root weights (27.0 g and 17.3 g, respectively). In contrast, *Raphanus sativus* generally showed significant ($p < 0.05$) growth responses compared to *E. sativa* across all treatments. Our results indicate that the combined application of *Glomus mosseae* with peatmoss is an effective strategy to significantly improve the early growth and nutrient uptake of radish and arugula in poor soils.

1. INTRODUCTION

The radish (*Raphanus sativus*) plant is one of the vegetables widely consumed all over the world. It is mostly native to Europe. The plant grows widely in the Arab world and belongs to the Brassicaceae family. *Raphanus sativus* consists of leaves and roots [1]. It is a root vegetable widely consumed around the world. Numerous studies have demonstrated the medicinal and nutritional values of radishes. *Raphanus sativus* extracts have been used to treat many disorders [2]. The radish plant also contains some minerals, such as calcium, iron, magnesium, zinc, manganese, and phosphorus [3].

The arugula (*Eruca sativa* Mill.) plant is an annual winter herbaceous plant from the Brassicaceae family. It is believed to be native to Central Asia and Europe, and its presence was recorded in Iraq. The *Eruca sativa* plant has a dark or dark green colour and is between 20 and 50 cm high. Its leaves are lyre-shaped to feathery, while its flowers are white and yellow with purple veins. *Eruca sativa* seeds are oval in shape [4]. Gulfraz et al. [5] reported that *Eruca sativa* tercress plant contains several secondary metabolic compounds, such as flavonoids, alkaloids, tannins, phenols, and saponins, with high biological activity. In a study conducted by Rani et al. [6], they observed that *Eruca sativa*'s leaves, seeds, and flowers contained substances that inhibited the growth of certain bacteria and fungi.

The mycorrhizal fungus *Glomus mosseae* is a species of arbuscular mycorrhiza (AM), forming highly branched dendritic structures inside cells called arbuscular shrubs [7]. There are several types of mycorrhizal fungi, among which some are of major environmental, physiological, and economic importance. These fungi are associated with the roots of more than 80% of vegetable crops [8]. The plant absorbs phosphorus from the mycorrhizae through the dendritic plasma membrane through the process of active transport by phosphate transporters. It also supplies nitrogen through nitrate transport. A study observed an increase in the transport of nitrate reductase from the fungi towards the plant in the form of ammonium (NH_4) and amino acids [9]. Smith and Read [10] reported the ability of AM fungi to absorb potassium, calcium, sulfur, iron, manganese, copper, and zinc and transport them to the plant through the roots. Mycorrhizae are present naturally in saline environments [11]. Mycorrhizal fungi play an indirect role in increasing the uptake of essential mineral nutrients and enhancing plant cell wall growth [12]. Mycorrhizal fungi and plant roots can interact in a symbiotic relationship to enhance plant productivity under both normal and abnormal environmental conditions [13].

The present research focused on the synergetic influence of *Glomus mosseae* and peatmoss in improving clay soil due to the fact that clay soils are generally compacted, not aerated, and are inhibitors of the root growth and development of the microorganisms. Peatmoss enhances the physical properties of clay soil by increasing the porosity, water-holding capacity, and aeration of the soil, which provides a better root environment. This physiological advantage improves root growth and allows colonization by mycorrhizal. The action of these effects is augmented by *Glomus mosseae*, which increases nutrient acquisition, especially phosphorus and micronutrients, due to the widespread hyphae. The enhanced soil structure brought about by the use of peatmoss enhances the survival and proliferation of the fungi, as well as the fungus, promoting the nutrient availability and proportion of carbon to the plants, leading to a mutually reinforcing interaction. This type of synergy has been widely reported to enhance the growth of plants, root biomass, and nutrient-use efficiency, particularly in nutrient-restrained or structurally confined soils such as clay [7, 10].

The present study aimed to evaluate and compare the influence of the mycorrhizal fungus *Glomus mosseae* on the growth and development of *Raphanus sativus* (radish) and *Eruca sativa* (arugula) plants under controlled conditions.

2. MATERIALS AND METHODS

2.1 Materials

The arbuscular mycorrhizal inoculant (*Glomus mosseae*) was procured from the Horticulture Department of the Research and Studies Directorate, Ministry of Agriculture. The formulation comprises a dry blend of pre-inspected soil containing spores, mycelium, and inoculated root pieces.

2.2 Methods

2.2.1 Preparation of the soil

For this study, the soil utilized was obtained from the surface horizon (0-30 cm depth) and consisted of a clay-loam mixture. The soil sample was subjected to air-drying and mechanical sieving using a 2 mm diameter sieve. A nutrient-reduction wash was then carried out by immersing the soil in water within a container. The nutrient-reduction wash lowers pre-existing soluble nutrients in the soil, standardizing growth conditions and minimizing background fertility, thereby ensuring that observed plant or microbial responses are primarily due to the applied experimental treatments. The mixture was stirred and permitted to stand for 15 seconds, facilitating the sedimentation of sand and coarser particles. The supernatant, which contained the unwanted silt and dissolved nutrients, was carefully removed. This decantation process was repeated four times to guarantee the production of a sandy, nutrient-depleted soil [14].

2.2.2 Determination of the germination percentage of the experimental plants

Twenty (20) seeds of each plant (*Raphanus sativus* and *Eruca sativa*) were sown independently in soil-filled container pots and maintained under appropriate watering, temperature, and humidity. Then the seed germination percentage was calculated for both plants according to Eq. (1).

$$Germination\ percentage = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds} \times 100 \quad (1)$$

2.2.3 Experimental design

For each plant species, a total of 35 kg of sterilized and leached soil was allocated for each plant species under investigation. The substrate was distributed into 12 experimental pots, representing six treatments and a control, each carried out in triplicate. A fungal biofertilizer (5 g of *Glomus mosseae*) was applied at a depth of 3 cm employing the pillow application method [15]. After that, the pots were filled with 750 ml of water each (half the field capacity) and covered with 50 grams of sterilized mixed soil. The plants were then monitored and watered as needed to keep the soil moist. Treatment details are presented in Table 1.

Table 1. The germination percentage of test plants in the different treatments

Treatment	Test Plant			
	Raphanus sativus		***Eruca sativa***	
	No. of Growing Plants	% Germ	No. of Growing Plants	% Germ
Clay soil (control)	10	50	9	45
Peatmoss	11	55	10	50
Clay soil + peatmoss	12	60	11	55
Clay soil + mycorrhiza	13	65	12	60
Peatmoss + mycorrhiza	15	75	14	70
Clay soil + mycorrhiza + peatmoss	17	85	15	75
LSD (0.05)	2.00*		2.34*	

% Germ: germination percentage.

2.2.4 Calculation of mycorrhizal determinants and testing infection efficiency

Six root samples were collected from each treatment every week for four weeks of cultivation in order to assess the degree of mycorrhizal infection. Thirty randomly selected 1-cm-long root pieces from each mycorrhizal treatment were then dyed with Acid Fuchsin dye to examine the roots inhabited by mycorrhizae. The percentage of mycorrhizal frequency and the weight of the mycorrhizal roots were calculated.

a) Mycorrhizal colonization frequency (%) in the root system: The microscopic frequency percentage of the root system was calculated according to the method described in the study by Owusu-Bennoah and Mosse [15], using Eq. (2).

$$\text{Colonization frequency (\%)} = \frac{\text{Number of colonized root fragments}}{\text{Total root fragments examined}} \times 100 \quad (2)$$

b) Mycorrhizal root dry biomass (g/plant): This was

determined using Eq. (3).

$$Mycorrhizal\ root\ dry\ biomass\ (g/plant) = Root\ system\ dry\ weight \quad (3)$$

2.2.5 Measurement of the vegetative parameters of the test plants

Plant height was measured from the soil surface (plant base) to the tip of the apical meristem of the main shoot using a measuring tape. Fresh weights of shoots and roots were recorded immediately after harvest using an analytical balance. For dry weight determination, plant samples were oven-dried at 70 ℃ until a constant weight was achieved (approximately 48 hours) before weighing.

2.2.6 Measurement of the root system

The roots of the selected plants were carefully excavated, separated from shoots, and washed on a perforated sieve under running water to remove soil. Air-drying was performed on the washed root samples with a filter paper before measurements. For the two plant species under study, the following biometric data were collected, and laboratory analysis was conducted.

a) *Root system length (cm):* This was measured from the crown to the root tip using a measuring tape. The values obtained from the root length measurement from each experimental unit were averaged.
b) *Root system weight (g):* The roots of the test plants were harvested from each experimental unit. The fresh weight was determined, and the average weight per plant was subsequently calculated.
c) *Fresh root-to-shoot ratio:* The root-to-shoot ratio (R/S ratio) was determined by dividing the fresh weight of the root system by the fresh weight of the shoot.
d) *Percentage of major elements (NPK) in the roots:* After four weeks of planting, the plant samples were taken from the roots using tap water, then distilled water, and dried at 70 ℃ using an electric dryer until the weight was stable. After that, they were ground and mixed evenly using the method described by Pairunan et al. [16] and Agiza et al. [17] and the elements were estimated according to the method described by Tandon [18].
e) *Protein content in leaves and roots:* After four weeks of growth, the nitrogen content was used to estimate the root protein percentage.

2.2.7 Statistical analysis

The Statistical Packages of Social Sciences (SPSS) [19] program was used to detect the effect of treatments and period in study parameters. Least significant difference (LSD) (ANOVA two-way: 3 treatments by 4 weeks and 6 treatments by 4 weeks/ type: *Raphanus sativus and Eruca stiva*) was used to significantly compare means in this study.

3. RESULTS AND DISCUSSION

3.1 Effect of mycorrhizal inoculation and soil amendments on seed germination

After four weeks of planting, the results of the germination percentage of *Raphanus sativus* and *Eruca sativa* for the various treatments (Table 1) revealed that both plants had similar germination rates, with the highest percentage of germination in *Raphanus sativus* (85%), and the mycorrhizal rate of *Eruca sativa* was recorded as 75%. The highest germination rate was observed in the clay soil treatment amended with both mycorrhiza and peatmoss. This enhanced germination percentage can likely be attributed to the synergistic relationship established between the plant roots and the mycorrhizal fungus *Glomus mosseae*. The fungus facilitated improved phosphorus uptake by the plants, enhancing its conversion into plant-available forms. This process was further supported by the detected activity of the enzyme acid phosphatase, which was visually identified on the mycorrhizal hyphae [20]. It has been reported that *Funneliformis mosseae* (AM) colonization improved the status of mineral nutrients, such as phosphorus (P), manganese (Mn), calcium (Ca), potassium (K), copper (Cu), zinc (Zn), and iron (Fe). Increased plant growth and chlorophyll content were also observed in plants colonized with AM fungi [21]. It is assumed that this is due to the dual interaction of the two substances added to the clay soil [22]. These germination percentages occurred for both plants in addition to the physical characteristics of clay soil, such as its porosity and ability to retain soil moisture. However, the radish and the arugula in the peatmoss treatment had a germination growth percentage of 55%, 60% respectively, which is attributed to the peatmoss. It is considered an enhancer of the physical and chemical properties of soil rather than a source of nutrients, and these findings are consistent with previous research [23].

3.2 Effect of soil type and *Glomus mosseae* inoculation on mycorrhizal root colonization

The percentage of mycorrhizal frequency (F%) in the roots of *Raphanus sativus* and *Eruca sativa* increased significantly in all inoculation treatments with the fungus *Glomus mosseae*, according to the results (Table 2). After four weeks of cultivation, the mycorrhizal and clay soil treatment recorded the highest percentage of radish plants (88.84%), followed by the same treatment for *Eruca sativa* (70.63%). The mycorrhizal and peatmoss treatment recorded the lowest percentage of mycorrhizal frequency for the *Raphanus sativus* and *Eruca sativa* plants (48.84% and 37.06%, respectively). The results further indicated that the percentage of mycorrhizal frequency in *Raphanus sativus* was consistently higher than that observed in *Eruca sativa* across all treatments and sampling weeks. These findings align with Daynes et al. [24], who observed superior mycorrhizal activity in nutrient-deficient clay soils. Conversely, the high nutrient availability and acidic nature of peatmoss created a suppressive environment, leading to diminished colonization rates. This observation may be due to its trace element content, which suppresses mycorrhizal efficiency. In contrast, mineral-poor environments facilitate AM association and enhance nutrient uptake (NPK, Cu, Zn), improving photosynthesis and organic carbon supply to the fungi. This mutual exchange of nutrients between plant roots and fungi enhances host plant growth and supports mycorrhizal colony expansion [25].

3.3 Effect of *Glomus mosseae* and soil type on mycorrhizal root dry weight

As illustrated in Table 3, the weight of the mycorrhizal dry roots of *Raphanus sativus* and *Eruca sativa* increased significantly in all treatments of the fungus *Glomus mosseae*.

Based on the root dry weight results, the mycorrhizal and clay soil treatment of *Raphanus sativus* showed the highest value four weeks after planting, reaching 0.79 g/plant, followed by the same treatment for *Eruca sativa*, which reached 0.51 g/plant. The mycorrhizal + peatmoss treatment produced the highest mycorrhizal dry root weight, reaching 0.49 and 0.33 g/plant for *R. sativus* and *E. sativa*, respectively. Across all treatments and sampling weeks, *Raphanus sativus* and *Eruca sativa* showed higher mycorrhizal dry root weights over the four-week period. The weight of mycorrhizal dry roots may have increased because mycorrhizae give the plant large amounts of essential nutrients like NPK and other elements and substances, which enhance plant growth and boost photosynthesis and other critical processes. In exchange, the fungus receives photosynthates (organic carbon) from the plant, which causes the colonies to grow. Mycorrhizae in the roots supply the plant with nutrients, water, and other elements, which leads to an increase in the percentage of mycorrhizal frequency. Since there is a direct correlation between the two, the weight of the mycorrhizal roots increases for the previously stated reasons. Additionally, washing the soil resulted in the presence of phosphorus in trace amounts, which enhanced activity. According to what was stated, the mycorrhizal mixture results from the absence of components in the soil that raise the rate of mycorrhizal frequency, which is directly proportional to the increase in the weight of mycorrhizal roots [24]. Mycorrhizal fungi often cause an increase in fungal biomass and a decrease in root biomass, which can diffuse through narrow soil pores, thereby improving nutrient uptake in the soil. This is particularly true for fungi [26].

Table 2. Effect of the mycorrhizal frequency (F%) of *Glomus mosseae* on the roots of the test plants during four weeks of cultivation

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil + mycorrhiza	22.48	45.57	67.53	88.84	**56.11 ± 4.71**	14.64	32.12	55.38	70.63	**43.19 ± 6.83**
Peatmoss + Mycorrhiza	12.59	25.72	38.14	48.84	**31.32 ± 4.06**	8.34	15.68	25.16	37.06	**21.56 ± 2.79**
Clay soil + mycorrhiza + Peatmoss	18.95	33.73	47.61	60.68	**40.24 ± 6.17**	11.64	20.38	32.95	52.58	**29.39 ± 4.55**
Mean: Period	**18.01 ± 1.26**	**35.01 ± 3.74**	**51.09 ± 5.22**	**66.12 ± 5.02**	---	**11.54 ± 1.08**	**22.73 ± 4.63**	**37.83 ± 4.17**	**53.42 ± 5.48**	---
LSD (0.05)	**Treat.: 4.854 *, Period: 8.241 *, Treat. × Period: 11.646 ***					**Treat.: 3.257 *, Period: 6.105 *, Treat. × Period: 8.691**				

Table 3. Effect of the weight of mycorrhizal dry roots (g/plant) of *Glomus mosseae* on the roots of the test plants during four weeks of cultivation

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil + mycorrhiza	0.16	0.22	0.45	0.79	**0.41 ± 0.08**	0.09	0.14	0.30	0.51	**0.26 ± 0.02**
Peatmoss + Mycorrhiza	0.07	0.12	0.28	0.49	**0.24 ± 0.03**	0.05	0.09	0.20	0.33	**0.17 ± 0.02**
Clay soil + mycorrhiza + Peatmoss	0.13	0.15	0.32	0.55	**0.29 ± 0.03**	0.08	0.12	0.22	0.39	**0.20 ± 0.03**
Mean: Period.	**0.12 ± 0.02**	**0.16 ± 0.02**	**0.35 ± 0.04**	**0.61 ± 0.02**	**---**	**0.07 ± 0.01**	**0.12 ± 0.02**	**0.24 ± 0.03**	**0.41 ± 0.03**	**--**
LSD (0.05)	**Treat.: 0.453 *, Period: 0.924 *, Treat. × Period: 1.121 ***					**Treat.: 0.371 *, Period: 0.792 *, Treat. × Period: 1.021 ***				

3.4 Influence of mycorrhizal activity and soil amendment on vegetative growth length of the test plants

The results presented in Table 4 showed a significant increase in the length of the vegetative part growth (cm) of *Raphanus sativus* treated with mycorrhizae and peatmoss compared with the control treatment (clay soil) over a period of four weeks. In contrast to the lowest values in the control treatment, which came to (15.1 and 12.5 cm) in *Raphanus sativus* and *Eruca sativa*, respectively, during the same weeks, the values in the clay soil, mycorrhizae, and peatmoss treatments reached their maximum after four weeks (27 and 21 cm, respectively). The findings also show that for all treatments and during the same weeks, *Raphanus sativus* and *Eruca sativa* had high length of all vegetables.

3.5 Effect of mycorrhiza and soil amendments on fresh shoot biomass of the test plants

A significant increase in the fresh weight of the shoots (g) of *Raphanus sativus* plants treated with mycorrhizae and peatmoss was observed compared with the control treatment (clay soil) over a period of four weeks (Table 5). The values (22.4 and 16.5 g) of the mycorrhizae, peatmoss, and clay soil treatment reached their maximum after four weeks of cultivation for the *Raphanus sativus* and *Eruca sativa* plants,

respectively, compared to the lowest values in the control treatment. Clay soil reached (6.9 and 3.1 g) in the *Raphanus sativus* and *Eruca sativa*, respectively, during the same period. The results also indicated that the fresh vegetative parts system was higher in the *Raphanus sativus* plant compared to the *Eruca sativa* plant for all treatments during the same period.

Table 4. The length (cm) of the vegetative part of *Raphanus sativus* and *Eruca sativa* plants at different treatments

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil (control)	8.5	10.0	12.2	15.1	**11.45 ± 0.87**	7.0	8.6	10.3	12.5	**9.60 ± 0.87**
Peatmoss	10.1	12.4	15.0	18.6	**14.03 ± 1.02**	8.8	10.3	12.9	15.3	**11.83 ± 0.92**
Clay soil + peatmoss	11.2	13.9	18.1	22.0	**16.30 ± 1.66**	9.8	11.9	14.3	17.0	**13.25 ± 1.03**
Clay soil + mycorrhiza	12.3	15.0	19.5	24.1	**17.72 ± 1.52**	10.9	13.4	15.9	19.2	**14.85 ± 0.86**
Peatmoss + mycorrhiza	13.1	16.0	21.2	25.5	**18.95 ± 1.98**	11.1	14.1	16.8	20.3	**15.57 ± 1.25**
Clay soil + mycorrhiza + peatmoss	14.2	17.2	22.4	27.0	**20.20 ± 2.26**	12.5	15.1	17.6	21.0	**16.55 ± 1.09**
Mean: Period.	**11.57 ± 1.04**	**14.03 ± 0.91**	**18.07 ± 1.47**	**22.05 ± 1.66**	---	**10.02 ± 0.92**	**12.23 ± 0.85**	**14.63 ± 0.93**	**17.55 ± 1.07**	---
LSD (0.05)	**Treat.: 3.667 *, Period: 3.158 *, Treat. × Period: 4.351 ***					**Treat.: 2.891 *, Period: 2.642 *, Treat. × Period: 3.235 ***				

Table 5. The weights (g) of the fresh vegetative parts of *Raphanus sativus* and *Eruca sativa* plants at different treatments

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil (control)	3.1	4.0	5.3	6.9	**4.83 ± 0.57**	1.4	2.0	2.9	3.1	**2.35 ± 0.08**
Peatmoss	4.3	5.5	7.4	9.7	**6.72 ± 0.42**	1.8	2.8	3.9	5.2	**3.43 ± 0.17**
Clay soil + peatmoss	5.2	6.6	8.0	10.1	**7.47 ± 0.61**	2.5	3.8	5.4	7.4	**4.77 ± 0.25**
Clay soil + mycorrhiza	6.4	8.4	10.9	13.5	**9.80 ± 0.73**	3.4	5.0	7.0	9.3	**6.17 ± 0.36**
Peatmoss + mycorrhiza	8.0	10.6	13.7	17.1	**12.35 ± 1.14**	4.5	6.5	8.0	10.2	**7.30 ± 0.41**
Clay soil + mycorrhiza + peatmoss	10.0	13.1	17.0	22.4	**15.62 ± 1.58**	6.0	9.0	12.6	16.5	**11.03 ± 0.8**
Mean: Period.	**6.17 ± 0.32**	**8.03 ± 0.81**	**10.38 ± 0.77**	**13.28 ± 1.03**	---	**3.27 ± 0.18**	**4.85 ± 0.35**	**6.63 ± 0.51**	**8.62 ± 0.49**	---
LSD (0.05)	**Treat.: 4.894 *, Period: 4.341 *, Treat. × Period: 6.537 ***					**Treat.: 3.805 *, Period: 3.124 *, Treat. × Period: 4.987 ***				

Table 6. The length (cm) of the root part of *Raphanus sativus* and *Eruca sativa* plants at different treatments

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil (control)	3.1	4.3	6.5	9.2	**5.77 ± 0.35**	2.0	2.9	4.2	6.1	**3.80 ± 0.09**
Peatmoss	3.9	5.1	6.9	10.5	**6.60 ± 0.54**	2.2	3.3	4.9	7.3	**4.42 ± 0.24**
Clay soil + peatmoss	5.0	6.5	8.9	12.1	**8.12 ± 0.78**	2.9	4.5	7.5	11.4	**6.57 ± 0.37**
Clay soil + mycorrhiza	6.3	8.0	11.7	15.2	**10.30 ± 0.72**	3.9	5.8	9.6	12.5	**7.95 ± 0.38**
Peatmoss + Mycorrhiza	7.7	9.6	13.6	17.2	**12.02 ± 0.91**	5.0	7.0	11.1	15.2	**9.57 ± 0.82**
Clay soil + mycorrhiza + peatmoss	9.0	11.1	15.7	20.5	**14.07 ± 0.94**	6.2	8.4	12.5	16.8	**10.97 ± 0.89**
Mean: Period.	**5.83 ± 0.41**	**7.43 ± 0.66**	**10.55 ± 0.78**	**14.12 ± 0.96**		**3.70 ± 0.18**	**5.32 ± 0.27**	**8.30 ± 0.76**	**11.55 ± 0.91**	
LSD (0.05)	**Treat.: 4.737 *, Period: 4.013 *, Treat. × Period: 5.742 ***					**Treat.: 3.819 *, Period: 3.126 *, Treat. × Period: 4.417 ***				

Table 7. The weights (g) of the tender root portion of *Raphanus sativus* and *Eruca sativa* plants at different treatments

Treatment	*Raphanus sativus*					*Eruca sativa*				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Mean: Treat.**
Clay soil (control)	3.3	4.5	6.7	9.9	**6.10 ± 0.41**	1.1	2.2	3.4	5.3	**3.00 ± 0.19**
Peatmoss	4.3	5.6	8.7	11.2	**7.45 ± 0.38**	2.1	3.3	5.1	7.8	**4.57 ± 0.24**
Clay soil + peatmoss	5.8	7.4	10.8	15.6	**9.90 ± 0.72**	3.2	4.7	6.1	9.7	**5.92 ± 0.33**
Clay soil + mycorrhiza	7.8	10.8	14.0	18.5	**12.77 ± 0.87**	4.5	6.1	8.2	11.0	**7.45 ± 0.41**
Peatmoss + mycorrhiza	9.9	12.9	16.7	20.6	**15.02 ± 0.84**	5.3	7.2	10.6	15.1	**9.55 ± 0.67**
Clay soil + mycorrhiza + peatmoss	11.9	15.8	21.5	27.0	**19.05 ± 1.16**	6.9	9.0	13.9	17.3	**11.78 ± 0.83**
Mean: Period.	**7.17 ± 0.67**	**9.52 ± 0.82**	**13.07 ± 0.94**	**17.13 ± 1.04**		**3.85 ± 0.26**	**5.42 ± 0.32**	**7.88 ± 0.68**	**11.03 ± 0.84**	
LSD (0.05)	**Treat.: 5.711 *, Period: 5.063 *, Treat. × Period: 6.7422 ***					**Treat.: 4.628 *, Period: 4.153 *, Treat. × Period: 5.146 ***				

3.6 Effect of mycorrhiza and soil amendments on root length of the test plants

The results (Table 6) showed a significant increase in the length of the root part (cm) of *Raphanus sativus* and *Eruca sativa* treated with mycorrhizae and peatmoss compared to the control treatment (clay soil) over a period of four weeks. In contrast to the lowest values in the control treatment, clay soil, which reached 9.2 and 6.1 cm in *Raphanus sativus* and *Eruca sativa* during the same weeks, the values in mycorrhizae, peatmoss, and clay soil reached their maximum after four weeks (20.5 and 16.8 cm) in *Raphanus sativus* and *Eruca sativa*, respectively. Additionally, the results showed that for all treatments and for the same weeks, *Raphanus sativus* had a longer root portion than *Eruca sativa*.

3.7 Variation in fresh root biomass between the test plants under mycorrhizal treatments

As shown in Table 7, fresh root weight (g) increased over the four-week period, and the inoculated treatments produced higher values than the control. At week 4, the combined treatment (clay soil + mycorrhiza + peat moss) recorded the highest fresh root weight (27.0 and 17.3 g for *Raphanus sativus* and *Eruca sativa*, respectively), whereas the control (clay soil) recorded the lowest values (9.9 and 5.3 g, respectively). Across all treatments and sampling weeks, fresh root weight was consistently higher in *R. sativus* than in *E. sativa*.

The results presented in Tables 4-7 indicated that mycorrhizal treatment in clay soil and peatmoss resulted in higher values than the control, peatmoss alone, or the combined peatmoss–clay soil treatment. Increased chlorophyll content in radish plants may contribute to enhanced vegetative biomass. Studies [27, 28] found that mycorrhizal inoculation increases leaf area, leaf number, leaf chlorophyll, and nutrient (N, P, K) uptake, leading to greater fresh weight in *Raphanus sativus* than in *Eruca sativa*. Increased root length may result from improved phosphorus and micronutrient absorption mediated by mycorrhizae, which also strengthen stress tolerance and root development. Moreover, mycorrhizal hyphae enhance potassium uptake, water balance, and root surface area [10].

The increased growth of the plants in the presence of combined mycorrhizal and peatmoss treatments could be explained by the complementary nature of the functions. The peatmoss enhances soil physical characteristics such as porosity, aeration, and water holding capacity, which generate a conducive microenvironment that supports the activity of arbuscular mycorrhizal fungi (AMF). Better soil structure helps increase the growth of hyphae and nutrient diffusion, and AMF increase the acquisition of phosphorus and micronutrients in low-availability environments [10, 29]. Such synergy is the reason behind high germination, biomass development, and root development observed under the combined treatments.

Chen and Aviad [30] reported that the increase in plant height is attributed to enhanced shoot growth, which improves nutrient absorption, thereby stimulating photosynthesis and promoting upward growth of the apex, resulting in plant elongation. It also activates some hormones, such as cytokinin, which stimulates cell division, and auxin, which helps in cell elongation. This is consistent with the results obtained in the current study. In the longest roots of *Raphanus sativus* and *Eruca sativa*, the mycorrhizal fungus *Glomus mosseae* supplies the plant with zinc (Zn) [31], which contributes to the synthesis of the amino acid tryptophan, a precursor of the natural hormone indole-3-acetic acid (IAA), thereby promoting cell expansion and elongation [32]. The amount of protein found in *Raphanus sativus* leaves is higher than in *Eruca sativa* leaves [33].

The elevated chlorophyll content in *Raphanus sativus* plants may contribute to increased vegetative weight. Studies reported that mycorrhizal inoculation enhances leaf area, leaf number, chlorophyll content, and nutrient (N, P, K) uptake, resulting in higher fresh biomass of *Raphanus sativus* compared to *Eruca sativa*. The observed root length increase is likely due to improved phosphorus and micronutrient absorption facilitated by mycorrhizae, which also enhance stress tolerance and root system development [34]. Additionally, extensive mycorrhizal hyphae enhance potassium and nutrient uptake, improve water relations, and increase root surface area [10]. *Raphanus sativus* is a root vegetable, and the roots of both plants are rich in chemical and biological compounds. Since the roots of *Raphanus sativus* develop into edible storage organs, they have been the focus of numerous studies and research. The diversity of root systems may lead to improved symbiotic relationships and mycorrhizal growth [24]. All results demonstrated a significant increase in the growth of all studied traits in *Raphanus sativus* across all treatments compared to *Eruca sativa* [29].

The persistent improvement in mycorrhizal colonization and growth response when using *Raphanus sativus* over *Eruca sativa* could be connected with the variations in root system structure and physiological requirements. R. sativus forms a

bulkier storage-type root system and allocates more carbon beneath ground that may improve fungal colonization and maintain symbiotic relationship, *Eruca sativa*, on the contrary, has finer and more fibrous root system, which can restrict the scope of colonization and carbon provision to the fungus. The identity of the host plant is an established factor that dictates the effectiveness and successful outcomes of AMF colonization [35].

There was a high positive correlation between the frequency of mycorrhizal colonization, root biomass, and the indicators of plant growth, such as fresh weight and shoot height. Increased colonization increases the effective absorptive surface area of the roots, water relations, nutrient uptake (particularly P, Zn, and K), and photosynthesis and vegetative development [36]. The results do concur with past studies, which suggest that AMF colonization degree is a good predictor of growth increase in mycorrhizal crops grown in a nutrient-limited environment.

4. CONCLUSION

The findings of the current study demonstrated a symbiotic relationship between *Raphanus sativus* and *Eruca sativa* Mill with the fungus *Glomus mosseae*, which enhanced plant growth in the presence of peatmoss and clay soil. This effect is attributed to the nutrients, porosity, moisture, and essential elements, such as organic carbon, provided by these substrates, which support fungal activity. The fungi also provide phosphorus and their ability to absorb nutrients and growth regulators. From this, we conclude that diverse root systems, coupled with a suitable environment, can enhance these symbiotic relationships. The experiment of this study was a short-term pot experiment carried out in a controlled environment; thus, it might not be applicable directly to open-field agriculture systems. Only one mycorrhizal species was used in the experiment, and the variety of soil amendments was small, and the soil physicochemical properties and native microbial communities were not characterized in detail. Moreover, the reactions of plants were considered at the initial stages of growth, and parameters associated with yield were not examined. The future studies need to consider the long-term field experimentation on a variety of soils and climatic conditions, with multiple species and consortia of arbuscular mycorrhizal species. The extent of mycorrhizal colonization and functional activity should be quantified through the use of advanced molecular tests. More research is also needed to investigate the efficiency of nutrient-use and stress tolerance, crop production, and economic viability to reinforce the practical use of mycorrhizal biofertilizers in sustainable farming.

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