Response of potato plants to different treatments of the mycorrhizal fungus *Glumus moseae* isolated from the roots of *Imperata cylindrical* L.

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Abstract:

The host plant's ability of absorbing nutrients and water is enhanced by the symbiosis between mycorrhizal fungi and its roots. In order to assess this, a field study has been carried out in a completely randomized design (CRD) with five replicates and four inoculums of mycorrhizal hyphae (10 g, 25 g, 50 g, 100 g) containing fungal spores from the plant's roots. Measurements have been made of the mycorrhizal characteristics, soil properties, element availability, and some mineral and physiological elements in leaves. The percentages of nitrogen, auxin, phosphorus, manganese, and chlorophyll increased as the amount of inoculum increased, according to the findings of plant testing. This was particularly true for M3 treatment, where the average values were 70.88 mg/g, 60.78, 4.43, 0.5, and 97.52 parts per gram. While treatment M4 outperformed all other treatments in terms of proline, potassium, copper, zinc, and iron percentages (91.93, 4.17, 2.88, 24.58, and 12.08 parts per million, respectively), soil test results indicated that treatment M3 had higher levels of nitrogen, phosphorus, and potassium elements (32.96, 0.34, and 88.48 parts per million, respectively), and treatment M4 had higher levels of infection severity and spores (100, 100%, and 160 spores g. soil -1, respectively).

Key words: Response, Glumus moseae, Mycorrhizal, Imperata cylindrical.

Introduction:

Arbuscular mycorrhizal fungi (AMF) belong to the phylum Glomeromycotina (Zou *etal*., 2021). Based on how they interact with host plant's roots, arbuscular mycorrhizal fungi are divided into two groups: septate mycorrhizal fungi, which surround tips of host plant's roots, and arbuscular mycorrhizal fungi, whose hyphae enter and develop in plant roots' cells (Abdel-Raheem et al., 2024). Woody plants, including angiosperms and gymnosperms, which include both non-flowering and flowering groups, have AMF colonies encircling all of their roots. They create a symbiotic relation between a fungus and a plant known as mycorrhizal symbiosis,

which is a complex filamentous network with high absorption efficiency. Whereas the fungi give the plant water and mineral nutrients, including nitrogen and phosphorus, in addition to that they acquire carbon from photosynthetic products of the plant, like sugars and fatty acids. Plant health and, therefore, the functioning regarding the plant ecosystem are all positively impacted by such nutritional exchange, as are the fundamental nutrient and soil cycle processes (Lin et al., 2025). Transporting and absorbing nutrients for plants is the primary role of mycorrhizae (Luginbuehl et al., 2017; Abdel-Raheem et al., 2014). In practically all plants, AMF improves nutrient absorption, particularly for phosphorus (Nije et al., 2023; Nell et al., 2010). Under low phosphorus and nitrogen levels, it enhances plant development and growth (Liu et al., 2018). In plants not linked to AMF, it has been found that the transcription regarding the two transporter genes (PT6 and PT2) decreased. As opposed to direct uptake by roots, plants linked to AMF had higher transcription, which boosted P uptake (Jeong et al., 2015).

As the world's third-largest food crop (FAO, 2024), potatoes are vital to maintaining global food security due to their high nutritional and economic worth (Devaux et al., 2021). They are planted in no less than 125 nations and are considered a staple crop for human consumption because of population expansion (Villa, 2021) because of their digestibility, high yield, and richness in carbs and proteins (Fernandez-Lopez et al., 2020). One nutrient-rich plant protein that could be utilized in place of animal protein is potatoes. For conserving the genetic diversity of potatoes, international development organizations have started to take advantage of farmers' knowledge (Earle, 2020). According to Reddy et al. (2018), potatoes could be categorized as follows:

Kingdom: Plantae

Division: Magnoliophyta

Class: Magnoliopsida

Sub class: Asteridae

Order: Solanales

Family: Solanaceae

Genus: *Solanum*

Species: *S. tubersum*

As a result of ongoing human activity, soil pollution damages plants and lowers their nutritional value (Tang et al., 2019). Different plants react differently to mineral and salt stress. Through generating metal-resistant biomass, certain plants can endure and adjust to high metal concentrations (Fuentes et al., 2016a). With regard to stressed ecosystems, microbes in the root zone are thus crucial for promoting development and growth of the plant (Perezet *etal*., 2020; Vidal *etal*., 2020). Under mineral stress, microbes, like arbuscular mycorrhizal fungi, enhance plant growth (Herrera *etal*., 2018; Zhan *etal*., 2018; Ortiz et al., 2019). Many studies have also documented improvements in N nutrition through symbiosis between AMF and plants (Courty *etal*., 2015; Koegel *etal*., 2017). In this symbiosis, N is converted to positively charged arginine through the glutamate synthase/glutamate synthase cycle (Courty et al., 2015) and then absorbed in both inorganic (ammonium ions and nitrate) and organic (ammonium acids) forms (Leigh *etal*., 2009). Additionally, studies demonstrated that AMF inoculation increased the absorption regarding chelated iron, nitrogen, potassium, calcium, phosphorus, zinc, and et al. (Balliu *etal*., 2015; Li *etal*., 2016; Prasad *etal*., 2017; Etesami *etal*., 2021). The symbiotic relationship between the mycorrhizae and plant is strengthened under stress, which lowers the intake of sodium and chloride (Evelin *etal*., 2012; Rillig & Lehmann, 2015) and raises the nutritional value of elements (Lin *etal*., 2017; Wang *etal*., 2018). Through enhancing the host plant's water quality and stomatal opening, enhancing the photochemical capacity of PSll in the leaves (Gong et al., 2013; Boutasknit et al., 2020), increasing the chloroplasts' absorption efficiency, shielding pigments from harm, enhancing the chloroplast cycle (Bashir *etal*., 2020; Boutasknit *etal*., 2021), and lowering proline levels, Rasouli *etal*. (2023) reported that inoculation with AMF increased chlorophyll amount.

2- **Materials and methods:**

On September 21, 2024, a factorial experiment depending on a CRD has been carried out in Baqubah Nursery, which is affiliated with Diyala Agriculture Directorate. The experimentation had five replicates and four treatments of *Glomus mosseae* mycorrhizal inoculum (10g, 25g, 50g, and 100g) that contained spores as well as fungal threads from infected roots of the Halfa plant. The experiment had five rows, measuring 5 x 4 meters, with a meter between each row and a meter

between replicates. As a result, there were twenty experimental units total, with each plant being regarded as an experimental unit. The Ministry of Science and Technology's Research Center provided the Burren type of potato seeds *(Solanum tuberosum* L.).

2-1- **Preparing the seeds, soil, biofertilizer and planting:**

The land was prepared through splitting it into five lines and plowing it. The fungal inoculum (10, 25, 50, 100) g is represented by the remaining lines, whereas the first line denotes the control treatment. Along with a few heavy elements, the soil's salinity, texture, and acidity were determined, as shown in Table (1). The best potato seeds with sprouting were chosen. The esparto plant's roots, which was cultivated and multiplied on corn roots in plastic pots, were used to make the fungal inoculum. The number of spores as well as the severity regarding the infection were assessed after infected soil was removed from the corn plants. After that, peat moss was mixed with fixed amounts of the infected soil (Happer, 1981; Fracchia et al., 2001). For every row, a 15-cm-deep furrow was created. Five replicates per row of potatoes have been planted in the furrows, spaced one meter apart. Following the addition of the fungal inoculum to each of the four treatments, soil was applied to both the potatoes and the inoculum. A drip irrigation system was after that used for irrigating the soil.

2-3- **Plant tests:**

2-3-1 **Estimation of nitrogen content:**

The percentage regarding nitrogen in the samples has been estimated with the use of the Kjeldahl method, which was based on the technique Houba and Van Dijk (2008) mentioned. The sample, which had a known weight of about 5 g, was put in a beaker. A suitable quantity regarding a potassium sulfate as well as copper sulfate mixture was added to the sample, along with 25.0ml of concentrated sulfuric acid. The contents were heated to facilitate the digestion process. The mix had turned into a pale blue, clear liquid once the digestion was finished. The liquid was quantitatively moved to Kjeldahl apparatus's distillation flask, which holds a 40% concentrated solution regarding sodium hydroxide and is attached to a condensing distillation flask that ends in a test tube immersed in a receiving flask that contains a known boric acid volume (20%). Bromocresol blue

dye as well as methyl red indicator drops were added to the test tube. After that, the estimation flask was heated until it contained around 25 milliliters of collected distilled liquid. After that, a control solution (Blanck) was made from the aforementioned components, excluding the sample, and the collected liquid was filtered using hydrochloric acid (0.1). The next equation is used to determine the nitrogen percentage:

N% = Volume of HCl consumed x Molarity x0.014 / Weight of sample x100

2-3-2 **Estimation of phosphorus content:**

By weighing 0.50g of ground and dried sample and dissolving it in 2.0ml of perchloric acid and 5.0ml of sulfuric acid, the phosphorus content regarding the plant was measured with the use of the method that has been described by Pratt and Chapman (1961). With the use of the colorimetric approach, aluminum molybdate as well as ascorbic acid have been measured at 700 nm with a spectrophotometer.

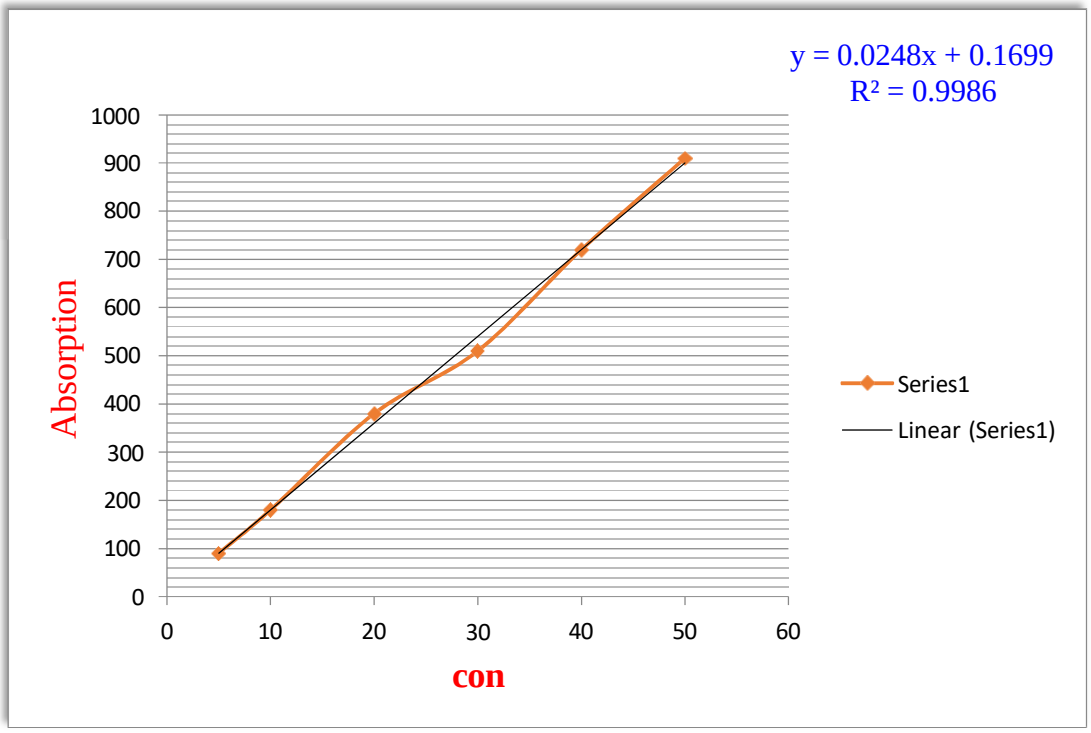

Fig. (1) Standard curve

2-3-3 **Estimation of potassium levels:**

The amount of potassium in the collected, dried, and ground plant samples has been measured. According to APHA 2017 procedure, the plant powder was digested by wet washing or acid digestion. A 25 ml Griffin beaker was filled with 3g of plant sample powder that needed to be digested, and after that 3 ml of a strong perchloric acid solution was added. A watch glass was used for covering the beaker, and it has been heated slowly on electric hot plate. To finish the digesting process, the temperature was progressively raised. We added three milliliters of concentrated nitric acid solution once again after letting the mix cool down to dry stage. Until the digestion process was finished, we kept the beaker covered and heated it further. The digestate we obtained was clear and pale in color. Five milliliters regarding diluted hydrochloric acid solution with water have been added after we had evaporated until we were almost dry. Following heating the mixture to a ratio of 1:1, we add distilled water for dissolving the remaining sample from the digestion process. Filtration is after that done to remove any remaining, undissolved materials, and the volume of the solution is adjusted to 50.0ml based on expected concentration in samples, making the sample ready for analysis. An atomic absorption apparatus of the SHEMADZU AA7000 type was used to test the absorbance of such digested samples.

2-3-4- **Estimation of the percentage of elements (Zn, Cu, Pb, Fe, Mg, Cd):**

The plant samples (which have been collected, dried, and ground) had their elements assessed. APHA approach (2017) called for either wet washing or acid digestion for digesting the plant powder. A 25 ml Griffin beaker was filled with 3g of plant sample powder that needed to be digested, 3ml of concentrated perchloric acid solution have been added after that, and the beaker has been covered with a watch glass. On electric hot plate, the mixture was heated gradually before the temperature was raised to finish the digesting process. After letting the mixture cool to dry stage, we added three milliliters of concentrated nitric acid solution once more, covered the beaker, and heated it further to the point where the digesting process was finished. We produced a clear, light-colored mixture known as "light colored digestate." We continued the evaporation process until we were almost at dry stage, at which point we added 5ml of a diluted hydrochloric acid solution with water at a 1:1 ratio. Following the process of digestion, we added

distilled water to dissolve the remaining sample, and we filtered it to remove any remaining as well as undissolved materials. The volume regarding the solution has been adjusted to 50.0ml based on the expected concentration in samples, making the sample ready for analysis. An atomic absorption device of the SHEMADZU AA7000 type was used to test the absorbance of such digested samples.

2-3-5- **Estimation of total chlorophyll content (mg/g-1 fresh weight):**

The method described through Dere et al. (1998) has been used to determine total chlorophyll content regarding the leaves. One gram of plant model has been cut to small pieces as well as crushed in a ceramic mortar with ten milliliters of acetone at 80% concentration. The filtrate and precipitate were then separated with the use of a centrifuge set to 3000 rpm for a period of 15 minutes. Until the green pigment disappeared from precipitate, the procedure regarding separating the filtrate from precipitate was carried out multiple times. An ultraviolet spectrophotometer was then used for measuring the filtrate's optical density at wavelength values of 645 and 663nm. The percentages of chlorophyll b, chlorophyll a, and total chlorophyll were determined using the next equations:

Total Chlorophyll (mg/gm) = [20.2 (D645) – 8.02 (D645)]

Where:

(V) = final volume of filtrate (ml), (D) = instrument reading, (W) = sample weight

2-3-6- **Indole acetic acid (IAA) determination**:

Twenty milliliters of methanol were used for extracting three grams of plant tissue that had been weighed as well as crushed in a mortar and pestle. Centrifugation was used to purify the extract at 5000 rpm/10 min. A new tube was filled with the resultant upper liquid. To preserve IAA, pH regarding the plant extract has been raised to over 9 ml using 1 M potassium hydroxide. Prior to partitioning against ethyl acetate, the sample was made more polar by adding 1 volume of pure water (2 ml) from ethyl acetate as well as 5ml of distilled water to the final extract. Centrifugation at 5000 rpm was used for separating the aqueous and organic phases, and the lower aqueous phase has then been moved to a new tube (Yeo et al., 2006).

HPLC apparatus

• Mobile phase: Methanol: 2% acetic acid (70:30)

• C18-ODS column (25cm x 4.6mm)

• Detector: UV 273nm

• Flow rate: 1.2mL/min

2-3-7- **Estimation of proline percentage:**

The following is the procedure used by Bates et al. (1973) to measure proline in plant tissue cells:

1. Add 5 milliliters of 3% sulfosalicylic acid to 0.5 milligrams of plant tissue. In a ceramic beaker, thoroughly crush the mixture until it is homogeneous.

2. For separating the filtrate from precipitate, centrifuge the mixture for a period of 10 minutes at 2000 rpm.

3. Make a solution through dissolving 1.25g of ninhydrin in 30ml of concentrated glacial acetic acid as well as 20ml of 30% phosphoric acid. Then, take 2ml of the filtrate and add 2ml of glacial acetic acid and 2ml of acidified ninhydrin solution.
4. After a period of 30 minutes of heating the mixture to 100°C in a water bath, let it cool.

5. To extract the proline from mixture, add 5 milliliters of 98% concentrated toluene.
6. Use a Vortex mixer to shake the samples for 30 seconds at maximum speed.
7. Use a pipette for removing the toluene layer after letting the samples settle for five minutes.

8. Determine the proline concentration by classifying each treatment with the use of the next equation as well as measuring the color intensity utilizing a spectrophotometer set at 520 nm:

Proline / Fe.wtg = (reading × 4 × 5/wt.in g) × 1.47

2-4- **Soil tests:**

2-4-1- **Ready Nitrogen:**

In accordance with Bremner method outlined in (Black, 1965), the ammonium ion has been extracted from the soil with the use of 2M KCl potassium chloride solution, and it was then distilled utilizing Kjelda apparatus utilizing magnesium oxide (MgO) and Divarda alloy.

2-4-2- **Ready phosphorus:**

Using 0.5N sodium bicarbonate at pH 8.50, the available phosphorus in the soil has been extracted using Olsen & Sommers method. After that, ascorbic acid as well as ammonium molybdate were used to create the blue color. As stated in (et al., 1982 Page), the phosphorus was after that measured at a wavelength of 882 nm with the use of a spectrophotometer.

2-4-3- **Ready potassium:**

Ammonium acetate solution (2N) was used for extracting the potassium from the prepared soil, and a flame photometer was used to measure the amount of potassium extracted, as described in Black (1965) and Ali et al. (2014).

2-4-4-**Estimation of elements (Pb, Cu, Cd):**

Achakzai et al. (2012) approach was used to determine the soil elements. The following elemental analysis has been carried out in the University of Baghdad's College of Science central laboratory:

1. A 15 ml test tube was filled with 0.2 g of weighted soil. After adding two to three milliliters of perchloric acid (HClO) and one milliliter of concentrated sulfuric acid (H2SO4) to the tube, the sample was allowed to digest for a whole day.

2. After that, the samples have been put in a water bath set at 100^{o}C until the solution turned clear and colorless, signifying that digestion was complete. Then, the samples have been allowed to cool.

3. After filtering the samples into 100 ml beakers, distilled water was added to bring the content up to 50 ml.

4- A flame atomic absorption spectrometer was used to measure the amounts regarding heavy elements in the samples of digested soil solution. The next equation was used for expressing the results in parts per million of dry soil weight:

Element concentration (mg kg-1) = (instrument reading × dilution factor) / (sample weight)

2-4-5- **Estimation of mycorrhizal characteristics**:

2-4-5-1- **Estimation of the percentage of roots infected with mycorrhizae (%)**:

The percentage of infection at the end of the season was estimated in the laboratories of the Agricultural Research Department - Integrated Pest Control Center - Ministry of Science and Technology in Zafaraniya.

2-4-5-2- **Estimation of injury severity (%)**:

We used the root staining technique outlined by Phillips and Hayman (1970). The roots have been properly cleaned under running water, then cut to 1cm-long pieces and put in 20-ml glass vials. The solution has been mixed with 10% KOH solution. After that, the roots have been placed for fifteen minutes in a water bath that was set at 70°C. After the solution has been poured out, distilled water was used for washing the roots three times. They added a 1% solution of H2O2. Ten minutes were spent with the roots at room temperature. Following the removal of solution, distilled water was used to thoroughly wash the roots. The addition of 1% HCl was made. At room temperature, the roots were immersed in the solution for three minutes. After that, without washing the roots, the acid was drained out. Lastly, acid fuchsin, which was made in the lab in accordance with Korinek et al. (1980), was used to stain the roots.

- 63 ml calicerin
- 875ml Lactic acid
- 63ml distilled water
- 0.1g acid fuchsin dye

The roots have been immersed in a water bath set at 70 ^{o}C for a period of 15 mins after the dye was added. After that, ten pieces per slide of the roots were placed on each glass slide, and they have been inspected under a light microscope. The formula outlined by Giovannetti and Moses (1980) was used for the determination of the infection rate. The next equation was used to determine the infection rate with the use of mycorrhizal fungi:

Infection percentage = Number of infected root segments × 100 / Total number of root cuttings examined (Dhiyab, 2012)

Regarding mycorrhizal infection severity, the next gradation was used:

Degree	Percentage of infected parts of the root segment
1	%0 - No injury
2	1 – 25 % infected from the root
3	26 – 50 % infected from the root
4	51 – 75 % infected from the root
5	76 – 100 % infected from the root

The following gradation was used to the severity regarding mycorrhizal infection:

Severity of injury = Total (number of infected pieces x degree of colonization) × 100 / Total number of examined plots × highest degree of settlement

2-4-5-3- **Calculating the number of mycorrhizal fungi spores (100 spores/g of dry soil):**

In the labs of the Ministry of Science and Technology's Agricultural Research Department's Integrated Pest Control Center in Zafaraniya, samples of 10 grams regarding soil around the roots of three wild plant species—Sudan grass, green foxtail, and Halfa—were taken for determining the number of mycorrhizal plant fungi. The suspension containing the spores has been moved to glass beaker and the volume has been increased to 250.0ml using the wet sieving and decanting procedure. To make it easier to collect spores at the suspension's surface, the supernatant was after tgat put in 0.50 ml plastic tubes and centrifuged for five minutes at 4000rpm without the addition of sucrose solution. The sediment was disregarded and the filtrate was removed from the tube. After that, the filtrate was put through sieves and rinsed with running water for one to two minutes. After that, it was moved to glass dish, and small tubes have been used for collecting the spores. The equation created by Gaur and Adholya (1994) was used to determine how many spores were present in 10 grams of soil.

Number of spores in 10 grams of soil = Average number of spores calculated in 1 ml × Final volume of suspension

2-4-6- **Electrical conductivity:**

With the use of Ec-meter, the electrical conductivity of a 1:1 soil:water extract was calculated utilizing the Black (1965) method.

2-4-7- **Soil reaction degree:**

With the use of pH meter, the degree of soil reaction in the soil extract has been calculated at a 1:1 ratio utilizing the technique described by Black (1965).

2-4-8 - **Soil organic matter content:**

The dry burning method, as described by Banin and Ben-Dor (1989), has been used in order to assess the amount of organic matter in soil.

2-4-9- **Soil texture:**

The soil texture at the plant sample sites has been ascertained using the procedure outlined by Page et al. (1982) and provided in Black (1965).

Table (1) shows chemical and physical analyses of the study soil.

Sample	Salinity Ds / cm	Ph	OM %	Pb ppm	Cu ppm	Cd ppm	K ppm	P ppm	N ppm	Soil separation ratio %		
Control	6.5	7.0	1.6	20.7	9.1	1.2	120.0	0.2	10.1	sand	gravel	clay
										60.0	23.0	17.0

3- **Results and discussion:**

3-1- **The percentage of elements in the leaves:**

The elements' leaf content has significantly increased, according to Figure (1)'s data. When biofertilizer was added, the amount of P, N, Mg, K, Cu, Zn, and F in

the leaves increased. In the N, P, K, and Mg elements, which were 4.42, 0.50, 4.15, and 97.4 parts per million, respectively, Treatment M3 performed better than all other treatments when put to comparison with the control treatment. The content of Zn, Cu, and F elements, which were 24.7, 2.89, and 12.36 parts per million, respectively, was superior than all other treatments thanks to Treatment M4. Because treatment M3 had the lowest percentage of Pb and Cd elements—0.51 and 0.65 parts per million, respectively—the addition of biofertilizer resulted in a considerable drop in the leaf content of these elements. The influence of the fungus is the cause of the variations in the leaf content of elements. According to Yang *etal*. (2020), Ghobadi et al. (2020), Lombardo *etal*. (2021), Ghobadi et al. (2024), and Carong *etal*. (2025), mycorrhizae improve the absorption of elements that are favorable to the plant and decrease the availability regarding other elements that harm the plant.

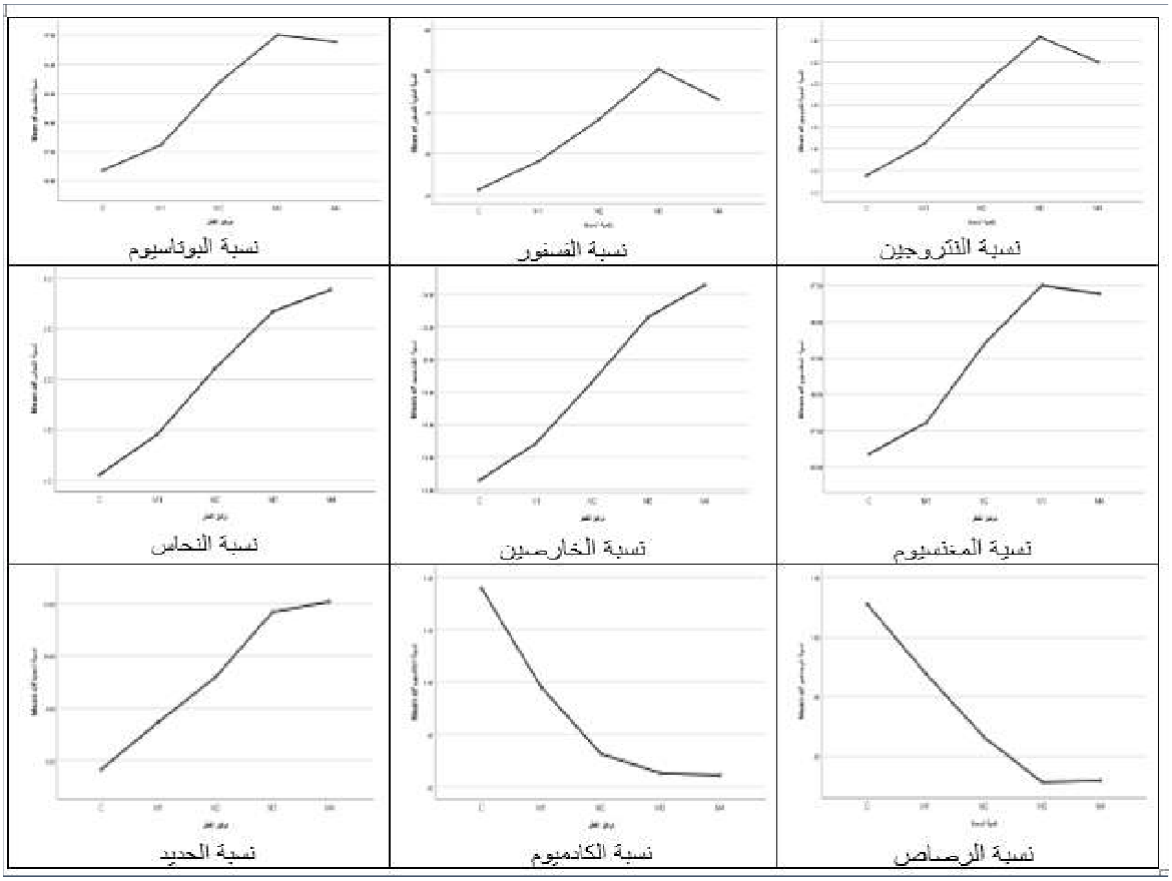

Figure (2) shows the average percentages of some elements in potato leaves as a result of using different treatments of biofertilizer.

3-2- **Chlorophyll content in leaves:**

With an average of 70.5 mg/g, treatment M3 performed much better than the other treatments, indicating that the percentage of chlorophyll in the leaves increased as the amount of biofertilizer increased (Table 2). This could be because inoculation with biofertilizer (mycorrhizae) improved the water quality, opened stomata, increased the efficiency regarding the second photosystem PII2, and increased the efficiency of plastid absorption (Boutasknit *etal*., 2020; Boutasknit *etal*., 2021; Farzad et al., 2023). It could also be because the amount of P and N in plant leaves increased (Quiroga *etal*., 2019; Balestrinie et al., 2020; Wu *etal*., 2021; Nije., 2023).

3-3- **The percentage of IAA in the plant leaves:**

As more pollen is given to potato plant, the auxin hormone content in the plant's leaf tissue increases, according to Table (2)'s findings. M3 treatment performed much better than all other treatments, indicating significant differences between the other treatments when put to comparison with the control treatment. This is because the plant tissue's increased auxin hormone content causes more cell divisions (Warnita et al., 2023).

3-4- **Proline percentage in plant leaves:**

TAs the amount of biofertilizer increased, proline accumulation increased as well. Treatment M4 performed better than all other treatments when put to comparison with the control treatment, which reached 91.93 parts per million. These results in Table (2) show that there are significant differences between treatments. The high proportion of salts as well as the contribution of biofertilizer to raising the proline percentage, improving osmosis and stress tolerance, is the cause of this. Proline functions as osmotic buffer, improves water absorption, and shields cells from the damaging effects regarding reactive oxygen species (Wu *etal*., 2013). Increased proline accumulation in plants treated with biofertilizer lessens photodamage to the thylakoid membrane, protects the enzymes involved in chlorophyll synthesis, and increases the osmotic potential gradient (Begum et al., 2019; Rasouli *etal*., 2023; Saman *etal*., 2019).

Table (2) shows the average values of the effect of four treatments of biofertilizer on the percentage of chlorophyll, proline and IAA in potato leaves.

Treatments	Chlorophyll content mg/g	Proline percentage	Auxin ratio (IAA)
Control	49.8	49.74	47.9
M1	52.4	51.79	50.6
M2	60.3	60.33	55.8
M3	70.5	75.95	66.3
M4	69.6	91.93	60.4

3-5- **Readiness of elements in the soil:**

According to Table (3)'s findings, there have been significant differences in the organic matter as well as element availability treatments. The amount regarding organic matter increased as more biofertilizer was added; the highest value, 2.64%, was found in treatment M4, which significantly outperformed all other treatments with an increase rate of 67.08%. In contrast, treatment M3 significantly outperformed all other treatments in terms of the availability of the elements N, P, and K, with their respective increase rates reaching 249.89, 88.88, and 60.51%. The availability of the elements Pb and Cd showed a decline in the average value, reaching 16.84 and 0.93 PPm, respectively, in treatment M3, however the availability of the element Cu showed a significant increase rate of 37.55%, outperforming all other treatments. Due to the mycorrhizal fungus's function, which increases the availability of certain elements because of their significance for plant growth and physiology and decreases the availability of other elements whose presence increases plant toxicity or because of genetic and environmental factors, and the fungus's relationship to the host plant, the average values of element availability fluctuate (Wang *etal*., 2022).

Table (3) shows average values of the effect of four treatments of biofertilizer on the value of organic matter and the availability of elements N, P, K, Pb, Cu, and Cd in potato soil.

Treatment	OM %	N	P	K	Pb	Cu	Cd
Control	1.58	9.42	0.18	117.42	20.74	8.84	1.18
M1	1.84	10.72	0.22	140.44	19.45	9.44	1.08
M2	1.88	25.14	0.28	145.48	18.04	10.04	1.02
M3	2.54	32.96	0.34	188.48	16.84	11.08	0.93
M4	2.64	28.50	0.29	181.62	17.04	12.16	1.02

3-6- **Infection rate, severity and number of spores:**

As the amount of biofertilizer increase, so did the infection severity, infection rates, and spore count in potato roots, according to Table (4) and Figure (1) data. Treatment M4 recorded the highest values for infection rate, infection severity, and spore count, totaling 100%, 100%, and 160 spores/g. soil-1, respectively, indicating substantial differences across treatments (Figure 2). This is a result of mycorrhizal fungi's efficacy and the host plant's response to the inoculum, which increases the plant's supply of phosphorus. Consequently, mycorrhizal fungi and potato plants develop a symbiotic association. Furthermore, the symbiotic association between mycorrhizal fungi and roots is strengthened by the chemical secretions of the roots in the root zone. These secretions contain substances that promote the development of fungal spores, hence promoting infection (Naje et al., 2023).

Table (4) shows the percentage and severity of infection and the number of spores for four treatments of mycorrhizal fungi in potato plants

Tretments	Infection rate %	Severity of injury %	Number of spores (spore/gm. soil-1)
M1	60	65	70
M2	80	85	100
M3	90	95	140
M4	100	100	160

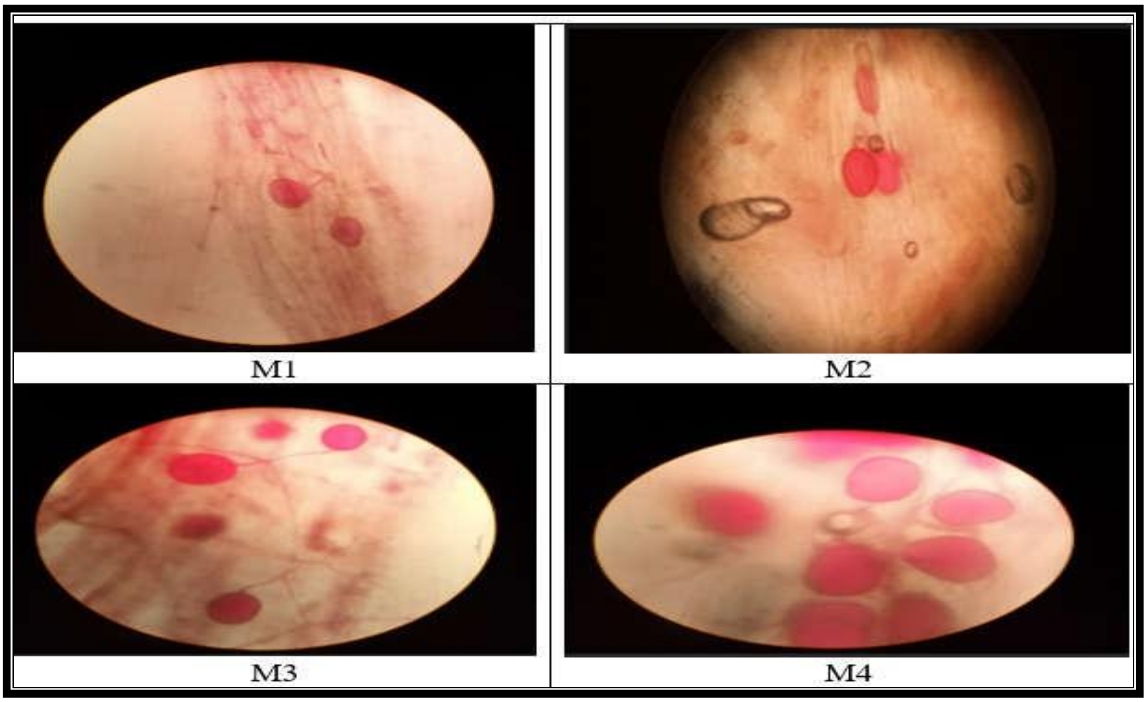

Image No. (1) shows the severity of the infection of potato plants with mycorrhizal fungi.

Conclusion:

The results show that there is an increase in most of the studied traits with increasing the amount of fertilizer used in the inoculation process, as treatment M3 recorded the highest average values in the majority of studied traits, and that the decrease in average values in some traits in treatment M4 despite the increase in the amount of fertilizer is a result of competition between the fungal colony and the plant for the food source. Inoculation also led to a decrease in the oxidative stress within the plant, which formed a negative correlation with the percentage of proline. The availability of heavy elements in soil and osmotic stress also decreased, which caused an increase in the availability of important elements for the plant and an increase in organic matter. Therefore, we can use biofertilizers instead of chemical fertilizers, as they are of a suitable cost and a renewable source of plant nutrients.

REFERENCES

Al-Salihi, N. S. (2024). Morphological and ecological study of endophytic mycorrhizal fungi on wild plants in Diyala Governorate. PhD thesis. College of Education for Pure Sciences. University of Diyala. Iraq.

Ali, N. S., Hamdallah, S. R. and Abdul Wahab, A. S. (2014). Soil Fertility. Ministry of Higher Education and Scientific Research. University of Baghdad. p. 307, Iraq.

Abdel-Raheem, M., Al Salihi, N. S., Al – Tamimi, S.A.Z. (2024). Mycorrhizae Symbiotic Relationship Between a Plant and a Fungus. Lambert Academic publishing.

Achakzai, A.; Majeed, O. L. and Oladel, J. B. (2012). Effect of mycorrhizal inoculation on the growth and phyto extraction of heavy metals by Maize grown in oil Contaminated Soil. pak. J. bot., 44 (1): 221-230.

APHA (American Public Health Association). (2017). Standard Methods for the Examination of Water and plant 23 th Edition, 800 I Street, NW, Washington DC, USA.

Balestrini, R., Brunetti, C., Chitarra, W., Nerva, L. (2020). Photosynthetic traits and nitrogen uptake in crops: which is the role of arbuscular mycorrhizal fungi? Plants 9, 1105.

Balliu, A.; Sallaku, G.; Rewald, B. (2015). AMF inoculation enhances growth and improves the nutrient uptake rates of transplanted, salt-stressed tomato seedlings. Sustainability. 7, 15967–15981.

Bates, L. S; Waldren, R. P. and Teare, L. D. (1973). Rapid determination of free proline for water-stress studies. plant and soil 39, 205-207.

Begum, N., Ahanger, M. A., Su, Y., Lei, Y., Mustafa, N. S. A., Ahmad, P., et al. (2019). Improved drought tolerance by AMF inoculation in maize (Zea mays) involves physiological and biochemical implications. Plants 8, 579. doi: 10.3390 /plants8120579.

Ben-Dor, E. and A. Banin. (1989). Determination of organic matter content in aridzone Soils using asimple“ loss-on-ignition” method. Commun. *Soil Sci. plant Anal*., 20 (15-16):1675-1695.

Black, C. A.(ed). (1965 b). Methods of soil analysis. part 2. chemical and Microbiological properties No.9. In the sevies Agronomy. Amer. Soc. Agron. Madison. Wis.

Black, C.A. (ed).(1965). Methods of soil analysis.Part 2.chemical and Microbiological properties No.9. In the sevies Agronomy .Amer.Soc.Agron.Madison.Wis.

Boutasknit, A., Baslam, M., Ait-El-Mokhtar, M., Anli, M., Ben-Laouane, R., Ait Rahou, Y., et al. (2021). Assemblage of indigenous arbuscular mycorrhizal fungi and green waste compost enhance drought stress tolerance in carob (Ceratonia siliqua l.) trees. Sci. Rep. 11, 1–23. doi: 10.1038 / s41598-021-02018-3.

Boutasknit, A., Baslam, M., Ait -El-Mokhtar, M., Anli, M., Ben-Laouane, R., Douira, A., et al. (2020). Arbuscular mycorrhizal fungi mediate drought tolerance and recovery in two contrasting carob (Ceratonia siliqua l.) ecotypes by regulating stomatal, water relations, and (in) organi adjustments. Plants 9, 80.

Carong, N.F.R., Carong, H. and Mantja, K. (2025). Arbuscular Mycorrhiza Fungi And Mineral Fertilizer Effects On Growth And Production Traits Of The

Potato (Solanum Tuberosum L.). SABRAO Journal of Breeding and Genetics, 57 (2) 752-760.

Chapman, H.D. and Pratt, P.F. (1961). Methods of analysis for soils, plants and

Courty, P.E.; Smith, P.; Koegel, S.; Redecker, D.; Wipf, D. (2015). Inorganic nitrogen uptake and transport in beneficial plant root-microbe interactions. Crit. Rev. Plant Sci. 34, 4–16.

Dere, S., Gunes,T. and Sivaci, R. (1998). Spectrophotometric determination ofchlorophyll- A, B and total carotenoid contents of some algae species usingdifferent solvents. Tr. J. of Botany, 22: 13-17.

Etesami, H.; Jeong, B.R.; Glick, B.R. (2021). Contribution of arbuscular mycorrhizal fungi, phosphate–solubilizing bacteria, and silicon to P uptake by plant. Front. Plant Sci. 12, 1355.

Evelin, H.; Giri, B.; Kapoor, R. (2012). Contribution of Glomus intraradices inoculation to nutrient acquisition and mitigation of ionic imbalance in nacl-stressed Trigonella foenum-Graecum. Mycorrhiza. 22, 203–217.

Farzad, R., Trifa Amini1, Skrovankova, S., Mohammad, A., Mohammad, B.H., Sezai, E., Martina, B., Martina, M and Jiri, M. (2023). Influence of drought stress and mycorrhizal (*Funneliformis mosseae*) symbiosis on growth parameters, chlorophyll fluorescence, antioxidant activity, and essential oil composition of summer savory (*Satureja hortensis* L.) plants. Front. Plant Sci. 14:1151467.

Gaur, A. and Adholya, A. (1994). Estimation of VAM spores in soil a modified method.mycorrhiza News (9),p:10-11.

Ghobadi, M., Dehnavi, M, M., Yadavi, A, R., Parvizi, K. and Zafari, D. (2020). Reduced P fertilization improves Fe and Zn uptake in potato when inoculated with AMF in P, Fe and Zn deficient soil. J. Rhizosphere. P: 1-8.

Ghobadi, M., Dehnavi, M, M., Yadavi, A, R., Parvizi, K. and Zafari, D. (2024). Mycorrhizae enhance minituber weight and nutrient content in potatoes transferred from *in vitro* to hydroponic culture under different phosphorus levels. Journal of Plant Nutrition. Volume 47, Issue 14.

Giovannetti, M. and Mosse, B. (1980). An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots – New phytol., 84:489-500.

Jeong, K.; Mattes, N.; Catausan, S.; Chin, J.H.; Paszkowski, U.; Heuer, S. (2015) Genetic diversity for mycorrhizal symbiosis and phosphate transporters in rice. J. Integr. Plant Biol. 57, 969–979.

Koegel, S.; Mieulet, D.; Baday, S.; Chatagnier, O.; Lehmann, M.F.; Wiemken, A.; Boller, T.; Wipf, D.; Bernèche, S.; Guiderdoni, E.; et al. (2017). Phylogenetic, structural, and functional characterization of AMT3;1, an ammonium transporter induced by mycorrhization among model grasses. Mycorrhiza.27, 695–708.

Kormanik,p.p.; Bryan,W.C. and Schultz,R.C. (1980). Procedure and equipment for staining numbers of plant root samples for endomycorrhizal assays. *Can.J.Micobiol*.,26: 536-538.

Lehmann, A.; Rillig, M.C. (2015). Arbuscular mycorrhizal contribution to copper, manganese and iron nutrient concentrations in crops—A meta-analysis. Soil Biol. Biochem. 81, 147–158.

Leigh, J.; Hodge, A.; Fitter, A.H. (2009). Arbuscular mycorrhizal fungi can transfer substantial amounts of nitrogen to their host plant from organic material. New Phytol. 181, 199–207.

Li, X.; Zeng, R.; Liao, H. (2016). Improving crop nutrient efficiency through root architecture modifications. J. Integr. Plant Biol. 58, 193–202.

Lin,J.; Wang, Y.; Sun, S.; Mu, C.; Yan, X. (2017). Effects of arbuscular mycorrhizal fungi on the growth, photosynthesis and photosynthetic pigments of Leymus chinensis seedlings under salt-alkali stress and nitrogen deposition. Sci. Total Environ. 576, 234–241.

Liu, X.; Yu, J.; Wei, J.; Qin, Y.; Shi, X.; Liu, K.; Jia, L. and Fan, M. (2025). Inoculation with arbuscular mycorrhizal fungi at the seedling stage of potatoes improves phosphorus use efficiency. Frontiers in Sustainable Food Systems.

Liu, C.; Ravnskov, S.; Liu, F.; Rubæk, G.H.; Andersen, M.N. (2018). Arbuscular mycorrhizal fungi alleviate abiotic stresses in potato plants caused by low phosphorus and deficit irrigation/partial root-zone drying. J. Agric. Sci., 156, 46–58.

Lombardo, S., Scavo, A.,, Abbate, C., Pandino, G., Bruno, P. and Giovanni, M. (2021). Mycorrhizal Inoculation Improves Mineral Content of Organic Potatoes Grown under Calcareous Soil. J. Agri, 11, 333.

Luginbuehl, L.H.; Menard, G. N.; Kurup, S.; van Erp, H.; Radhakrishnan, G.V.; Breakspear, A.; Oldroyd, G. E. D.; Eastmond, P.J. (2017). Fatty acids in arbuscular mycorrhizal fungi are synthesized by the host plant Science, 356, 1175 – 1178.

Mckinney, H.H. (1923). Influence of soil temperature and moisture on infection of wheat seedings by *Helminthosporium sativum*.*J.Agri.Res*., 26: 195-217.

Naji, S.N., Dhiyab, N.S., Abed, R.M. (2023). Efficincy of some local iolates of arbuscular mycorrhizae in the growth and prodactivity of potatoes (*Solanum tuberosum L.)* in plastic pots. plant science today. Vol 11 (1): 274-280.

Nell, M.;Wawrosch,C.;Steinkellner, S.; Vierheilig, H.; Kopp, B.; Lössl, A.; Franz, C.; Novak, J.; Zitterl-Eglseer, K. (2010). Root Colonization by symbiotic arbuscular mycorrhizal fungi increases sesquiterpenic acid concentrations in Valeriana officinalis L. Planta Med. 76, 393–398.

Page, A. L.; Miller, R. H. and Kenney, D.R. (1982). Methods of Soil analysis part (2). 2nd ed. Agronomy 9. Am.Soc. Agron. Madison, Wisconsin.

Page, A.L.; Miller, R.H. and Kenney, D.R. (1982). Methods of Soil analysis part (2). 2nded. Agronomy 9.Am. Soc. Agron. Madison, Wisconsin.

Phillips J.M. and Hayman, D.S. (1970). Improved procedures for clearing roots and staining parasitic and Vesicular arbuscular mycorrhizal fungi for rapid assessment of infection.Transactions of the British mycological Society,55(1):158-161.

Prasad, R.; Bhola, D.; Akdi, K.; Cruz, C.; KVSS, S.; Tuteja, N.; Varma, A. (2017). Introduction to mycorrhiza: Historical development. In Mycorrhiza-Function, Diversity, State of the Art; Varma, A., Prasad, R., Tuteja, N., Eds.; Springer: Cham, Switzerland, pp. 1–7.

Quiroga, G., Erice, G., Aroca, R., Chaumont, F., Ruiz-Lozano, J.M., (2019). Contribution of the arbuscular mycorrhizal symbiosis to the regulation of radial root water transport in maize plants under water deficit. Environ. Exp. Bot. 167, 103821.

Saman, K., Farhad, F., Nasser, A., Mehrdad, Y., and Farrokh,R. K. (2019). Effects of different irrigation regimes and two arbuscular mycorrhizal fungi on some physiological characteristics and yield of potato under field conditions. J. of plant nutrition. p 1-13.

van Dijk, D. and Houba, V.J.G. (2000) Homogeneity and Stability of Material distributed within the Wageningen Evaluating Programmes for Analytical Laboratories Commun. Soil. Sci.Plant.Anal, 31 (11-14), 1745-1756.

Wang, Y., Wang, X., Sun, S., Jin, C., Su, J., Wei, J., et al. (2022b). GWAS, MWAS and mGWAS provide insights into precision agriculture based on genotype-dependent microbial effects in foxtail millet. *Nat. Commun.* 13:5913. doi: 10.1038/s41467-022-33238-4 .

Wang, Y.; Wang, M.; Li, Y.; Wu, A.; Huang, J. (2018). Effects of arbuscular mycorrhizal fungi on growth and nitrogen uptake of Chrysanthemum morifolium under salt stress. PLoS ONE. 13, e0196408.

Warnita, Y. Y. and Suwinda, R. (2023). Growth response and yield of potato plant with applications of rhizobacteria and mycorrhizal. IOP Conf. Ser.: Earth Environ. Sci. p: 1-8.

Waters. University of California, Los Angeles, 60 - 61, 150-179.

Wu, M., Yan, Y., Wang, Y., Mao, Q., Fu, Y., Peng, X., Yang, Z., Ren, J., Liu, A., Chen, S., Ahammed, G.J., (2021). Arbuscular mycorrhizal fungi for vegetable (VT) enhance resistance to Rhizoctonia solani in watermelon by alleviating oxidative stress. Biol. Control. 152, 104433.

Wu, Q.-S., Srivastava, A. K., and Zou, Y.-N. (2013). AMF-induced tolerance to drought stress in citrus: a review. Sci. Horti. 164,77–87.

Yang,Q., Ravnskov, S., and Andersen, M, N. (2020). Nutrient uptake and growth of potato: Arbuscular mycorrhiza symbiosis interacts with quality and quantity of amended biochars. J. Plant Nutr. Soil Sci. 1–13.

Yeo-jae, K; Young, j. O and Woong, J. P. (2006). HPLC-based quantification of indole -3-acetic acid in the primary root tip of maize. JNBT, Vol 3, No 1, pp. 40-45.

Zou, Y.N.; Wu, Q.S.; Kuˇca, K. (2021). Unravelling the role of arbuscular mycorrhizal fungi in mitigating the oxidative burst of plants under drought stress. Plant Biol. 23 (Suppl. S1), 50–57.

Happer, C. M. (1981). Techniques for study the infection of plants by vesicular arbuscular mycorrhizal fungi under axenic conditions. new phytol.88.614.

Fracchia, S., Menendez, A., Godeas, A. and Ocampo, J. A. (2001). A method to obtain monosporic cuituves of arbuscular mycorrhizal fungi. soil biology and Biochemistry, 33, p: 1283 – 1285.