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Effect of Interaction Between Mycorrhizal Fungus and *Azotobacter Chroococcum* Bacteria on Some Physiological Characteristics and Heavy Metals of Potato Plant (*Solanum Tuberosum* L.)

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ABSTRACT

For the fall of 2024–2025, a pot experiment has been conducted at Diyala Agriculture Directorate-affiliated Baqubah nursery. Investigating the impact of mycorrhizal fungi and Azotobacter chroococcum bacteria's interaction on certain physiological characteristics as well as heavy elements regarding potato plants with the use of a randomized complete block design (RCBD) in sandy soil with a mixed texture The results showed that double inoculation with mycorrhizal fungi and azotobacter led to significant differences in the leaf NPK content, the leaf indole acetic acid (IAA), the leaf chlorophyll content, the number of bacteria in the soil, the number of mycorrhizal fungi spores, and infection rate and severity, which reached 4.767%. 0.610%, 4.660%, 74.400 µg mg-1 fresh weight, 81.567 mg g-1 fresh weight, 36×108 cfu g-1 soil, 16.00 spore g-1 soil, 81%, 91% respectively compared with the control treatment of 3.800%, 0.316%, 3.880%, 52.933 µg mg-1 fresh weight, 57.433 mg g-1 wet weight, 19×108 cfu, 5.00 spore g-1 soil, 49%, 54% respectively. Results have shown significant differences for the heavy elements Pb and Cd. The control treatment was significantly superior, reaching 0.900 ppm and 1.220 ppm, respectively, compared to the interaction treatment of 0.013 ppm, 0.020 ppm respectively. The results showed significant differences for each of Fe, Zn, Mg, and Cu. The interaction treatment was superior, reaching 14.690 ppm, 26.00 ppm, 111.600 ppm, and 3.650 ppm respectively, in comparison with the control treatment, which amounted to 6.250 ppm, 16.20 ppm, 90.700 ppm and 1.800 ppm respectively.

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1. Introduction

Rhizosphere microorganisms are crucial for preserving soil fertility, which is necessary for productive crop production for meeting the world's expanding food needs. Along with protecting plants from pathogens as well as producing a variety of growth regulators, the most significant of which are gibberellins and indole acetic acid, Plant Growth Promoting Microorganisms (PGPM) are either bacteria, such as *Azotobacter chroococcum*, which is one of the most effective and common free-living bacteria in fixing atmospheric nitrogen, particularly in nitrogen-poor or nitrogen-free environments. The majority of plants have a symbiotic interaction with soil organisms called cytokinins (Hindersah et al., 2020) or arbuscular mycorrhizal fungi (AMF), which enhance the host plants' production, growth, and nutrition supply. Thus, their significance as a biofertilizer in farming. Mycorrhizal fungi, which may colonize plant tissues more than any other form of organism, are vital parts regarding natural soil ecosystems. They contribute significantly to soil fertility because, along with secreting glomalin, such organisms cooperate with their roots for improving nutrition and increasing the surface area regarding the roots. This improves the water-holding capacity, porosity, and quality of soil (Adetunji et al., 2022). Because mycorrhizal fungi absorb other mineral nutrients, they lessen the negative effects of toxic elements on plants, allowing

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them to withstand high concentrations of heavy metals in polluted environments (Tahat et al., 2010).

A significant crop in Solanaceae family is potato. Originally from Latin America, this tuberous herbaceous plant is one of the most significant crops worldwide, particularly in sub-Saharan Africa. According to Hardigan et al. (2017), it is the third most significant crop that is grown for direct human consumption. Thus, the purpose of the presented research was to:

1- The impact of *Azotobacter* bacteria and mycorrhizal fungi and their interaction on some physiological traits of the potato plant.

2- The effect of adding mycorrhizal fungi and *Azotobacter* bacteria in improving the soil biological properties as well as the concentration of some heavy elements in the soil for potato crops.

2. Materials and Methods

Using 12 plastic pots with a 20-kilogram capacity, 40 cm diameter, and 40 cm height, the experiment has been conducted throughout the fall 2024–2025 growing season. Four pots have been assigned to every treatment, and every treatment had three replicates, thus sandy mixture soil was employed. The treatments have been as follows: M0 represented control treatment (no inoculation), M2 represented the Azotobacter bacterial inoculation, M1 represented the mycorrhizal fungal inoculation, and M3 represented the double inoculation of mycorrhizal fungi + Azotobacter bacteria. The R.C.B.D. was followed in the execution of experiment. The mycorrhizal bio-inoculum has been acquired from the Ministry of Science and Technology's Agricultural Research Department's Biotechnology Department. The spores have been separated using the wet screening technique outlined by Gerdemann and Nicolson (1963). The bacterial inoculum was acquired from the Biotechnology Department of the Agricultural Research Department, and 10 g was put to each pot. For isolating and propagating Azotobacter bacteria, the dilution and pour plates method was used, as it has been previously indicated through Davis et al. (2005). The isolate was purified and propagated using modified Ashby's Medium. For every liter of liquid broth, the inoculum was put onto sterile peat moss, and liquid cultures have been made for *A. chroococcus* isolate. It has a 1×107 density. The tubers to be inoculated were soaked in liquid vaccine for a while to allow adhesion to take place after the vaccine was combined with water and gum arabic added to improve adhesion. The experiment, which started on October 28, 2024, and finished on January 28, 2025, aimed to investigate the impact regarding the interaction between the Azotobacter bacteria and the mycorrhizal fungus on certain physiological traits and heavy elements of potato plant *Solanum tuberosum* L.

2.1 Calculating Mycorrhizal Infection Criteria

2.1.1 Calculating the Average Number of Mycorrhizal Fungal Spores in the Soil

The wet sieving and decanting approach had been used for taking 10 g of potting soil samples. After transferring the spore suspension to glass beaker, the volume has been increased to 250 ml. To make it easier to collect spores at the suspension's surface, the supernatant was subsequently put into 500 ml plastic tubes and centrifuged for 5min at 4000rpm without the addition of sucrose solution. The sediment was disposed of, and the filtered part 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 a glass dish, and fine tubes have been used to gather the spores. The formula equations by Gaur and Adholeya (1994) were used to determine how many spores were present in 10 g of soil.

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

2.1.2 Calculating the Percentage and Severity of Mycorrhizal Infection (%)

We used root staining techniques outlined by Phillips and Hayman (1970). The roots have been properly cleaned under running water, then cut to 1-cm-long pieces and put in 20-ml glass vials. They were treated with 10% KOH solution. After that, the roots spent fifteen minutes in a water bath set at 70^{o}C. After the solution was poured out, distilled water was used for washing the roots three times. They were mixed with a peroxide solution. After the roots were left at room temperature for 10 mins, the solution has been poured, they were thoroughly cleaned with distilled water, and then 1% hydrochloric acid (HCL) has been added. The roots were then left in the solution for 3 mins at room temperature, the acid has been poured without first washing them, and lastly, in accordance with Kormanik et al. (1980), the roots have been stained with acid fuchsin stain. The roots were placed in a water bath set at a 70^{o}C temperature for 15 mins after the dye was added. After that, ten pieces of the roots were moved to each glass slide, where they were viewed under a light microscope. The equation given by Giovannetti and Mosse (1980) was used to get the infection rate:

Percentage of infection = (infected root pieces/number) / (examined root pieces/total number) × 100

2.1.3 Severe Root Colonization by Mycorrhizal Fungi

Mycorrhizal colonization intensity is a quantitative measure calculated according to the following colonization index:

0: Uninfected tissue

1: 0-25% of infected tissue

2: 26-50% of infected tissue

3: 51-75% of infected tissue

4: 76-100% of infected tissue

The severity of mycorrhizal infection was calculated according to McKinney (1923)McKinney (1923) as follows:

Severity of mycorrhizal infection = ((Degree of colonization × Number of infected pieces) Total) / (Highest degree of colonization × Total number of pieces examined) × 100

2.2 Estimating the Percentage of NPK in Leaves

2.2.1 Nitrogen (%)

According to the next equation, the nitrogen content of the samples has been estimated with the use of Keldahl method, which was based on the technique described by Van Dijk and Houba (2000):

N% = volume of HCl consumed × standard × 0.014 / sample weight × 100

2.2.2 Phosphorus (%)

The method that was presented by Chapman and Pratt (1962) was used for estimating the plant's phosphorus content.

2.2.3 Potassium (%)

According to the procedure, potassium was measured in plant samples that have been collected, dried, and ground. The plant powder has then been digested by either wet washing or acid digestion.

2.3 Estimation of Total Chlorophyll Content (mg/g Fresh Weight)

The method described by Dere et al. (1998) was used for estimating the total chlorophyll content of leaves. The percentages of chlorophyll b, chlorophyll a, and total chlorophyll were determined with the use of the following equations:

$$\text{Total Chlorophyll (mg/mg)} = \frac{[20.20 \cdot D_{645} - 8.02 \cdot D_{645}] \times (v/1000)}{w}$$

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

2.4 Estimation of Heavy Elements in Plants (PPm)

According to the approach, elements have been calculated in plant samples that were collected, dried, and ground. The plant powder has then been broken down by either wet washing or acid digestion.

2.5 Determination of Indole Acetic Acid (IAA) in Leaves

Auxin content has been determined according to the approach of Kim et al. (2006).

A complete randomized block design was used for statistical analysis, and the Genstat software was used for comparing the means with the use of the least significant difference (LSD) at a 0.05 significance level (Al-Rawi & Khalaf Allah, 1980).

3. Results and Discussion

The nitrogen content regarding the leaves varied significantly (P≤0.05) among the treatments, as indicated by Table (1). M3 treatment had the highest nitrogen content, 4.767%, while M0 control treatment had the lowest, 3.800%, with 25.44% increase rate. The increase is caused by mycorrhizae increasing the surface area of the roots. This mechanism is further enhanced by the mycorrhizae hyphae's small diameter of 3–4 micrometers, which helps them penetrate the soil more easily than plant roots, which have a diameter of 10 micrometers. Hyphae absorb nutrients as well as water and transfer them to the roots, which subsequently transfers them to plant's vegetative parts (Ali et al., 2022).

Azotobacter bacteria are also significant because of their tremendous capacity for fixing nitrogen from the atmosphere and make it more available to plants. According to research, such bacteria may fix between 0.3 and 15 kg N h-1 of nitrogen annually in the soil, which lessens the need for fertilizers containing nitrogen, including urea (Bageshwar et al., 2017). The table's results showed that the

percentage regarding phosphorus in the leaves varied significantly between the treatments; M3 treatment had the highest value, reaching 0.610%, M0 control treatment had the lowest value, reaching 0.316%, with a 93.03% increase rate. This is because mycorrhizae, a phosphate biofertilizer, contributed by secreting the phosphatase enzyme and organic acids like carbonic acid, which dissolve in water and lower soil pH, making the elements—particularly phosphorus—more ready for plant roots to absorb. The phosphatase enzyme aids in the conversion of inaccessible organic phosphorus into plant-available mineral phosphorus (Parihar et al., 2020). According to Table (1), there have been significant differences (P≤0.05) in the leaf potassium content across treatments. Treatment M3 had the highest value, 4.660%, while treatment M0, the control, had the lowest value, 3.880%, with 20.10% increase rate. This is explained by the fact that Azotobacter bacteria are bacterial biofertilizers that increase the availability of certain nutrients that are required for the plant, like phosphorus, nitrogen, potassium, and other vital nutrients in plant life cycle, as well as stimulating plant growth and producing numerous plant growth regulators, which include cytokinins, auxins, and gibberellins (Salim, 2018).

Table 1: Shows how Inoculation with Azotobacter Bacteria as Well as Mycorrhizal Fungi, as Well as their Interactions, Affects the Amount of NPK in the Leaves of Potato Plant *Solanum tuberosum* L.

Treatments	N%	P%	K%
M0	3.800	0.316	3.880
M1	4.333	0.470	4.330
M2	4.633	0.550	4.513
M3	4.767	0.610	4.660
L.S.D 0.05	0.292	0.016	0.019

Table 2 reveals that there have been significant differences (P≤0.05) in leaf content regarding indole acetic acid (IAA) between treatments. M3 treatment had the highest value, at 74.400 micrograms mg-1 fresh weight, while the control treatment, M0, had the lowest value, at 52.933 micrograms mg-1 fresh weight, 40.55% increase rate. The growth regarding the vegetative group is improved by mycorrhizal fungi's capacity for producing growth regulators like cytokinins, auxins, and gibberellins, which promote the growth regarding root hairs as well as increasing the surface area that was available for nutrient absorption.

Through releasing hormones as well as growth regulators including cytokinins, gibberellins, and indole acetic acid (IAA), which can enhance plant development as well as nutrient absorption, Azotobacter bacteria directly affect plant growth (Smith & Read, 2008). The table 2 results demonstrated that there were notable variations in the amount regarding chlorophyll in the leaves across treatments. M3 treatment had the highest amount, 81.567mg/g of fresh weight, while the control treatment, M0, had the lowest amount, 57.433 mg/g. The fresh weight rose 42.02%. This is ascribed to the function of mycorrhizal fungi, which help plants that coexist with them produce more chlorophyll by increasing the number of leaf bundles as well as mesophyll layer cells. They also help plants through supplying a variety of nutrients, such as manganese (Hu et al., 2020). Since nitrogen is essential to the activity related to photosynthesis process and also enters the composition of amino acids, proteins, and cell protoplasm, the increase in percentage of nitrogen entering into the composition of chlorophyll—particularly that which is produced by Azotobacter bacteria—is the cause of the rise in chlorophyll concentration. A key function of biofertilization is the release of growth hormone cytokinin, which absorbs the potassium, iron, and magnesium that go into making chlorophyll molecule (Lalitha et al., 2004). The findings of Dheyaab (2012) regarding the potato plant are in line with this. According to Table (2), there have been notable variations in the leaf proline content between treatments. The control treatment M0 had the highest value, measuring 66.853 micrograms mg-1 fresh weight, while treatment M3 had the lowest value, measuring 50.300 micrograms mg-1 wet weight, with a 32.90% increase rate. This is because inoculation with biofertilizer reduced the proline content, which is in agreement with findings of Nadeem et al. (2006).

Table 2: Shows how Inoculation with Azotobacter Bacteria as well as Mycorrhizal Fungus Affects Certain Physiological Traits of Potato Leaves (*Solanum tuberosum* L.).

Treatments	Indole Acetic Acid (µg mg^{-1} Fresh Weight)	Chlorophyll (mg. g^{-1} Wet Weight)	Proline (µg mg^{-1} Fresh Weight)
M0	52.933	57.433	66.853
M1	63.200	69.800	60.200
M2	70.400	77.433	52.600
M3	74.400	81.567	50.300
L.S.D 0.05	0.621	0.110	0.080

When bio-fertilizer was added after the harvesting process, the average number of bacteria (36×108) cfu8 for azotobacter was higher than that of control treatment (19×108) cfu8, indicating the existence of significant differences (P≤0.05) in the number of bacteria, according to Table (3). This is explained by the beneficial effects of azotobacter biofertilization, which helps the plant get the nitrogen it needs from bacteria. Nitrogen is a component of proteins and amino acids, which improves the plant's vegetative growth as well as increases its weight. In return, the plant gives the bacteria the nutrients they want, which increases the quantity of bacteria in root area. This leads to an increase in root infection and the formation of bacterial root nodules.

Table 3: The Impact of Mycorrhizal Fungal as well as Azotobacter Bacterial Inoculation and their Interaction on Soil Bacterial Count (cfu.g of Soil)

Average Biofertilization	(cfu /g Soil)
Control	19×108
Mycorrhizal Fungi	26×108
Azotobacter Bacteria	36×108
Mycorrhizal Fungi+ *Azotobacter* Bacteria	27×108

Table (4) revealed that there have been significant differences (P≤0.05) in the number of spores in potato soil between the treatments. M3 treatment had the highest number, reaching 16.00 spores.g. soil-1, while M0 control treatment had the lowest number, reaching 5.00 spores g. soil-1, 220% increase rate. The table's and figure 1 finding demonstrated that there were notable variations in the infection rates across the treatments; M3 treatment had the highest rate, at 81%, while M0 control treatment had the lowest rate, at 49%, and 65.30% increase rate. The table's findings demonstrated notable variations in infection severity, with M3 treatment achieving the highest value at 91% and M0 control treatment reaching the lowest at 54%, representing 68.51% increase rate. Because the growth regulators, amino acids, organic acids, and free compounds secreted through Azotobacter bacteria help enrich the rhizosphere region with such compounds contributing to increasing the effectiveness regarding the mycorrhizal fungus, the (mixture) treatment's superiority in mycorrhizal characteristics is attributed to the organisms' synergistic work in the rhizosphere region (Pahari et al., 2017).

Table 4: Shows the Impact of Azotobacter Bacteria as Well as Mycorrhizal Fungus inoculation, as well as their Interactions, on Mycorrhizal Properties of Potato Plant Soil (*Solanum tuberosum* L.).

Treatments	Number of Spores (spore/gm.soil^{-1})	Infection Rate %	Infection Severity %
M0	5.00	49	54
M1	7.00	56	61
M2	12.00	70	75
M3	16.00	81	91
L.S.D 0.05	1.998	2.3	2.5

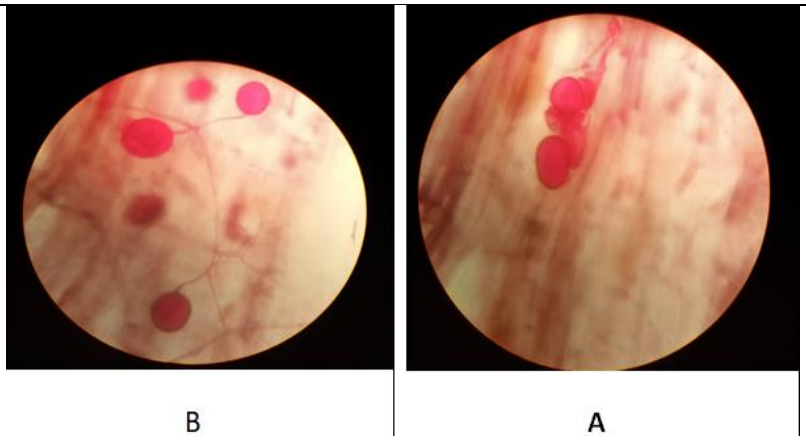


Figure 1: Shows (A) The Vesicular Structures in Treatment M1 (Mycorrhizal Fungi), B the Vesicular Structures in Treatment M3 (Overlap of *Azotobacter* Bacteria + Mycorrhizal Fungi

According to Table (5), there have been significant differences (P≤ 0.05) between treatments in lead element Pb. The control treatment M0 had the highest value, 0.900 mg kg. soil-1, while the treatment M3 had the lowest value, 0.013 mg kg. soil-1, with an increase rate of 6823.07%. The table's results indicated that there have been notable variations in cadmium levels. The control treatment, M0, had the greatest value at 1.220 mg kg. soil-1, while the M3 treatment had the lowest value at 0.020mg kg. soil-1, a

6000% increase rate. According to Wang et al. (2024), this is because mycorrhizal fungi help plants better withstand the toxic impacts of high cadmium as well as copper concentrations. According to the table's results, there were notable variations in the iron element Fe levels between treatments. M3 treatment had the highest value, measuring 14.690mg/kg soil, while the control treatment, M0, had the lowest value, measuring 6.250mg/kg soil, 135.04% increase rate. The table's findings demonstrated that there were notable variations in zinc element Zn levels across the treatments. M3 treatment achieved the highest value, 26.00mg/kg soil, whereas the control treatment M0 had the lowest value, 16.20 mg kg-1 soil, 60.49% increase rate. The table's results demonstrated that there were notable variations among the treatments for the magnesium element Mg. The M3 treatment achieved the highest value, totaling 111.600mg/kg. soil-1, while the control treatment M0 had the lowest value, totaling 90.700 mg kg. soil-1, with a 23.04% increase rate. According to the table's data, there were notable variations in the copper element Cu between treatments. M3 treatment had the greatest value, 3.650 mg kg. soil-1, while the control treatment, M0, had the lowest value, 1.800 mg kg. Since heavy metals have become an extended part of the food chain and affect human health, the increase of 102.77% in Soil-1 is because of the mycorrhizal fungi role in decreasing the toxicity of heavy metals in the soil. These fungi help plants withstand mineral stress because they have vesicles that resemble fungal vacuoles, which are where large amounts of heavy metals accumulate (Salman, 2018).

Table 5: The Inoculation Effect with Mycorrhizal Fungi and Azotobacter Bacteria and the Interaction Between them on Some Heavy and Nutritional Elements of Potato Leaves *Solanum tuberosum* L.

Treatments	Pb	Cd	Fe	Zn	Mg	Cu
M0	0.900	1.220	6.250	16.20	90.700	1.800
M1	0.723	0.800	10.250	20.30	95.700	2.440
M2	0.200	0.400	13.690	23.70	101.700	2.987
M3	0.013	0.020	14.690	26.00	111.600	3.650
L.S.D 0.05	0.169	0.163	0.020	1.049	0.199	0.108

4. Conclusions

Mycorrhizal fungi play an important role in the improvement of plant growth and increasing its productivity. Adding an integrated combination of biofertilizer (bacterial and fungal) gives the best results in all physiological and mycorrhizal characteristics and in tolerating heavy elements compared to single biofertilizer.

References

Adetunji, C. O., Anani, O. A., Thangadurai, D., & Islam, S. (2022). Arbuscular mycorrhizas: Applications in organic agriculture and beyond. *Organic farming for sustainable development*, 23-49.

Al-Rawi, K. M., & Khalaf Allah, A. M. (1980). Design and analysis of agricultural experiments. *El Mousel Univ., Iraq*, *19*, 487.

Ali, N. S., Allawi, M., & Majid, N. (2022). Rhizosphere management and agricultural sustainability. *Ministry of Higher Education and Scientific Research, University of Baghdad-College of Agricultural Engineering Sciences, Iraq*.

Bageshwar, U. K., Srivastava, M., Pardha-Saradhi, P., Paul, S., Gothandapani, S., Jaat, R. S., Shankar, P., Yadav, R., Biswas, D. R., & Kumar, P. A. (2017). An environmentally friendly engineered Azotobacter strain that replaces a substantial amount of urea fertilizer while sustaining the same wheat yield. *Applied and environmental microbiology*, *83*(15), e00590-00517.

Chapman, H. D., & Pratt, P. F. (1962). Methods of analysis for soils, plants and waters. *Soil Science*, *93*(1), 68.

Davis, K. E., Joseph, S. J., & Janssen, P. H. (2005). Effects of growth medium, inoculum size, and incubation time on culturability and isolation of soil bacteria. *Applied and environmental microbiology*, *71*(2), 826-834.

Dere, Ş., Güneş, T., & Sivaci, R. (1998). Spectrophotometric determination of chlorophyll-A, B and totalcarotenoid contents of some algae species using different solvents. *Turkish journal of Botany*, *22*(1), 13-18.

Dheyaab, N. (2012). The use of phosphate rock and superphosphate and the addition of fungal and bacterial fertilizers in the growth and yield of potatoes. In: College of Agriculture, University of Baghdad Republic of Iraq.

Gaur, A., & Adholeya, A. (1994). Estimation of VAMF spores in soil: a modified method. *Mycorrhiza news*, *6*(1), 10-11.

Gerdemann, J., & Nicolson, T. H. (1963). Spores of mycorrhizal Endogone species extracted from soil by wet sieving & decanting.

Giovannetti, M., & Mosse, B. (1980). An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New phytologist*, 489-500.

Hardigan, M. A., Laimbeer, F. P. E., Newton, L., Crisovan, E., Hamilton, J. P., Vaillancourt, B., Wiegert-Rininger, K., Wood, J. C., Douches, D. S., & Farré, E. M. (2017). Genome diversity of tuber-bearing Solanum uncovers complex evolutionary history and targets of domestication in the cultivated potato. *Proceedings of the National Academy of Sciences*, *114*(46), E9999-E10008.

Hindersah, R., Kamaluddin, N. N., Samanta, S., Banerjee, S., & Sarkar, S. (2020). Role and perspective of Azotobacter in crops production. *SAINS TANAH-Journal of Soil Science and Agroclimatology*, *17*(2), 170-179.

Hu, A., Xiao, D., Zhang, X., Wang, W., Li, K., & Sun, Y. (2020). Effects of salt stress on growth and photosynthetic fluorescence of two strains of Malus robusta rehd. *Non-Wood For. Res*, *38*, 208-215.

Kim, Y., Oh, Y. J., & Park, W. J. (2006). HPLC-based quantification of indole-3-acetic acid in the primary root tip of maize. *J Nano Biotech*, *3*(1), 40-45.

Kormanik, P. P., Bryan, W. C., & Schultz, R. C. (1980). Procedures and equipment for staining large numbers of plant root samples for endomycorrhizal assay. *Canadian Journal of Microbiology*, *26*(4), 536-538.

Lalitha, M., Babu, M. K., Ravisankar, C., & Rani, Y. A. (2004). Effect of bioregulators on chlorophyll content and keeping quality of betelvine (Piper betel L.).

McKinney, H. (1923). Influence of soil temperature and moisture on infection of wheat seedlings by Helminthosporium sativum.

Nadeem, S. M., Zahir, Z. A., Naveed, M., Arshad, M., & Shahzad, S. (2006). Variation in growth and ion uptake of maize due to inoculation with plant growth promoting rhizobacteria under salt stress. *Soil Environ*, *25*(2), 78-84.

Pahari, A., Pradhan, A., Maity, S., & Mishra, B. (2017). Carrier based formulation of plant growth promoting Bacillus species and their effect on different crop plants. *Int J Curr Microbiol App Sci*, *6*(5), 379-385.

Parihar, M., Chitara, M., Khati, P., Kumari, A., Mishra, P. K., Rakshit, A., Rana, K., Meena, V. S., Singh, A. K., & Choudhary, M. (2020). Arbuscular mycorrhizal fungi: Abundance, interaction with plants and potential biological applications. In *Advances in Plant Microbiome and Sustainable Agriculture: Diversity and Biotechnological Applications* (pp. 105-143). Springer.

Phillips, J. M., & Hayman, D. (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-IN118.

Salim, H. (2018). Efficacy of Bio-Fertilizers Pseudomonas fluorescens and Azotobacter chroococcum on Yield of Cabbage (Brassica oleracea L. Var. Capitata).

Salman, N. D. (2018). ISOLATION AND DIAGNOSIS OF MYCORRHIZA FUNGUS AND USED ON PHYTOREMEDIATION FOR SOIL TREATED WITH SEWAGE SLUDGE ANDGROWTH OF MAIZE PLANT. *Diyala Agricultural Sciences Journal*, *10*(1), 205-221.

Smith, S., & Read, D. (2008). Mycorrhizal Symbiosis, 3rd edn Academic Press. *San Diego, CA*.

Tahat, M., Kamaruzaman, S., & Othman, R. (2010). Mycorrhizal fungi as a biocontrol agent. *Plant Pathology Journal*, *9*(4), 198-207.

Van Dijk, D., & Houba, V. (2000). Homogeneity and stability of materials distributed within the Wageningen evaluating programmes for analytical laboratories. *Communications in soil science and plant analysis*, *31*(11-14), 1745-1756.

Wang, Q., Liu, M., Wang, Z., Li, J., Liu, K., & Huang, D. (2024). The role of arbuscular mycorrhizal symbiosis in plant abiotic stress. *Frontiers in Microbiology*, *14*, 1323881.