

The Role of Arbuscular Mycorrhizal Fungi and their Interaction with Tuber and Storage Root Crops (Such as Potato, Yam, Sweet Potato, Cassava, Carrot, Radish, Beetroot, Turnip, etc.) in Enhancing Yield

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Abstract: *Arbuscular Mycorrhizal Fungi (AMF) play a vital role in improving the growth and productivity of tuber and root crops, such as sweet potatoes, cassava, carrots, and radishes. Through symbiotic relationships with plant roots, AMF enhances nutrient and water uptake, offering significant benefits, particularly in nutrient - poor soils. This review explores the interactions between AMF and various tuber crops, focusing on their impact on root structure, physiological processes, and molecular mechanisms that contribute to improved yields. AMF promotes root colonization, enhances nutrient uptake efficiency, and supports the development of a more robust root system. The review highlights how AMF assists in nutrient absorption under both optimal and challenging conditions, such as drought, by improving plants' ability to tolerate environmental stress. Furthermore, the interaction of AMF with plant hormones like auxins and strigolactones is crucial for regulating root and shoot growth, ultimately influencing crop productivity. These findings suggest that AMF can significantly enhance plant growth and yield by improving root architecture and nutrient acquisition. A deeper understanding of these interactions can guide sustainable agricultural practices and demonstrate the potential of AMF inoculation to increase the productivity of tuber and storage root crops. Future research should focus on refining AMF inoculation techniques and exploring the genetic and environmental factors that influence AMF - plant symbiosis to maximize crop yields and resilience in diverse farming environments.*

Keywords: Arbuscular Mycorrhizal Fungi (AMF), Tuber and Root crop, Auxin, Citin Oligomers, Strigolactons.

1. Introduction

Sweet potato (*Ipomoea batatas*), a member of the *Convolvulaceae* family, is widely cultivated in tropical and subtropical regions due to its nutritional and economic value (Minemba et al., 2019). The crop's root system is vital for water and nutrient absorption, as well as for storing sugars produced during photosynthesis. However, low nutrient uptake and limited root differentiation are key factors hindering its production. Tuber crops, including sweet potato, cassava, and potato, exhibit diverse physiological and morphological traits and are primarily propagated vegetatively via stem cuttings, vine cuttings, or tuber sprouts. These crops are essential staples in tropical and temperate regions, providing carbohydrates, vitamins, and antioxidants crucial for human nutrition (Kondhare et al., 2021). Additionally, storage tubers and roots like yam, sugar beet, carrot, and radish play a significant role in food security and health due to their therapeutic potential, such as antimicrobial and antioxidative properties. Optimizing sweet potato production requires a focus on root morphology, which influences nutrient uptake efficiency. Studies have shown that soil quality, microbial activity, and fertilization practices significantly impact root development and yield (Wang et al., 2017). Recent advancements in in - vitro propagation techniques allow for the rapid production of

disease - free plants, though further improvements are needed for effective bio - hardening and field performance (Banerjee, 2006). Microbial inoculants, such as arbuscular mycorrhizal fungi (AMF), have demonstrated potential in enhancing root structure, nutrient availability, and water absorption (Maiti et al., 2016; Nanjundappa et al., 2019). This study aims to evaluate the performance of tissue - cultured sweet potato plants through bio - hardening techniques to improve their adaptability and productivity in field conditions.

Fresh sweet potato was cultivated in a field and treated with AMF (Arbuscular Mycorrhizal Fungi) (Figure.1). AMF was initially prepared by mixing it with cow dung, vermicompost, and soil in a 1: 1: 1 ratio. AMF powder was added to the soil at a concentration of 5g/L (N. V. Singh et al., 2016), and water was added as required. This mixture was stirred daily, covered with a polythene bag, and kept in a shaded area for 7 days. After 7 days, the mixture was integrated into the soil, and sweet potato plants were cultivated. Root samples were taken after 8 - 10 days for colonization studies, revealing the presence of AMF in small amounts in the roots (Figure.1) (Ildikó Hernádi et al., 2012). AMF structures, which began penetrating the roots within 3 - 4 days, were visible as circular formations surrounded by hyphae.

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Figure 1: Growth of trifoliate sweet potato (*Convolvulaceae*) influenced by Arbuscular Mycorrhizal Fungi (AMF) inoculation. The image shows the overall plant development: (A) with mycorrhizal treatment and (B) without mycorrhizal treatment (Chen et al., 2017).

AMF colonization rates vary across crop species due to differences in root structures. For instance, crops with denser root networks, like mung bean or soybean, show higher AMF penetration compared to tuber crops, where shorter roots and tuber formation may reduce AMF colonization (Lone et al., 2016). Despite these challenges, AMF enhances

water and nutrient uptake, promoting plant growth and tuber development (Ashok Aggarwal et al., 2011).

Physiological Interactions Between AMF and Storage Root Crops

Nutrient uptake is essential for plant growth and development. Plants absorb water and nutrients through their roots, influenced by environmental factors like soil conditions and water availability (H. Wang et al., 2006). AMF significantly aids in nutrient and water absorption, especially under drought conditions, by improving root water retention and nutrient uptake efficiency (Naheeda Bagum et al., 2019). This is achieved through the expansion of hyphal networks that connect root systems across the field, enhancing access to phosphorus, water, and other minerals while increasing resilience to abiotic stresses such as drought, salt, and metal toxicity (A. B. Haseena et al., 2022).

Table 1: Shows how AMF helps tuber and storage root crops grow better. It improves nutrient absorption and increases yield, and drought tolerance in crops like sweet potato, cassava, and yam.

Table 1: Interaction between Arbuscular Mycorrhizal Fungi (AMF) and Tuber/Storage Root Crops for Yield Improvement

S. No	Crop	AMF Species	Effects on Yield	Additional Benefits	Application	References
1.	Potato	<i>Rhizophagus irregularis</i>	Increased total yield and tuber size by 25%, supplied up to 90% plant phosphorus, and contributed significantly to nitrogen uptake.	Enhanced phosphorus uptake, improved nutrient absorption, boosted root health, increased disease resistance, and overall plant health improvement.	Applied AMF inoculants during planting, supported growth with reduced tillage and organic amendments, reducing chemical inputs, and improving crop resilience.	Yao et al. (2003), Al - Ani et al. (2013), Deja - Sikora et al. (2020), Lone et al. (2019), Saxena et al. (2020), Wu et al. (2022), and Croll et al. (2021).
2.	Yam	<i>Glomus spp.</i> , <i>Acaulospora spp.</i>	Increased tuber weight by 20% to 56% with <i>Glomus etunicatum</i> and <i>Gigaspora spp.</i> through improved nutrient uptake.	Increased secondary metabolite content (polyphenols, flavonoids, anthocyanins by 106%), improved root development, and disease resistance.	Enhanced root colonization and seasonal benefits, supported AMF with reduced tillage, and optimized nutrient uptake.	Chen et al. (2017), Lu et al. (2015), Don - Rodrigue et al. (2013), Tchabi et al. (2010), and Oyetunji (2007).
3.	Sweet Potato	<i>Glomus mosseae</i>	Improved tuber yield, biomass, growth, resulting in higher marketable yield.	Enhanced nutrient absorption, improved drought resistance, root morphology, disease resistance, and synergy with potassium fertilization.	Promoted root colonization with AMF inoculants, enhanced AMF effectiveness with reduced tillage, and optimized nutrient uptake.	Liu et al. (2014), Seemakram et al. (2023), Alhadidi et al. (2021), Tong et al. (2013), Yuan et al. (2023), Karthikeyan et al. (2021).
4.	Cassava	• <i>Glomus spp.</i> • <i>Acaulospora colombiana</i>	Root biomass and yield increased by 16.6% to 19.4% compared to controls, with dual inoculation and AMF - vermicompost combination improving biomass and reducing nematode growth.	Nutrient availability improved in poor soils, increasing (86%) phosphorus uptake, stress tolerance, nematode resistance, and plant growth.	Maximized cassava yield with AMF inoculants, organic amendments, and sustainable pest control.	Al - Hmoud & Al - Momany (2017), Silva et al. (2021), Pena V et al. (2021), Cavallari et al. (2021), Howeler et al. (2021).
5.	Carrot	<i>Acaulosporaceae</i>	Enhanced root biomass by 30%, combining AMF with vermicompost to reduce <i>Meloidogyne incognita</i> effects.	Improved soil structure, moisture retention, and pest resistance through AMF stimulation.	Utilized AMF inoculants to promote root colonization, enhanced AMF with organic amendments, and controlled pests to boost performance.	Prasad et al. (2017), Hussain et al. (2023), Chandrasekaran et al. (2021), Regvar et al. (2021).

6.	Radish	<i>Glomus spp</i>	Increased tuber fresh weight and root biomass by 20% to 30%, with improved radish yield compared to controls.	Enhanced nutrient uptake (phosphorus, potassium), alleviated allelopathic effects, improved stress tolerance, and maintained osmotic balance with AMF.	Enhanced root colonization with AMF inoculants, supported AMF with organic amendments, and combined sustainable pest control methods.	Mitra et al. (2019), Ma et al. (2022), Hussain et al. (2023), Regvar et al. (2021).
7.	Turnip	<i>Gigaspora spp.</i>	Higher yield and improved root quality, with AMF boosting biomass, increasing yield by 23%.	Enhanced soil nutrient dynamics, improved nutrient uptake, increased stress tolerance, better root development, and higher photosynthesis.	Maximized benefits using AMF inoculants, improving effectiveness with organic amendments and combining AMF with pest control.	Angelard et al. (2022), Hussain et al. (2022), Zhang et al. (2021), Alguacil et al. (2021), Ma et al. (2021), Rezaie et al. (2021).
8.	Beet root	<i>Rhizophagus irregularis</i>	Improved root development and approximately 23% increase in yield.	Increased phosphorus biomass by up to 43% and enhanced antioxidant levels in roots.	Used AMF inoculants during planting for root colonization, enhanced with organic amendments and reduced tillage.	Hussain et al. (2022), Saboor et al. (2021), Zhao et al. (2022), Liu et al. (2022).

Molecular Interactions Between AMF and Storage Root Crops

Symbiotic associations between AMF and plant roots play a crucial role in promoting root and plant growth (Khosro Mohammadi et al., 2011). AMF improves soil nutrient uptake, including phosphorus, nitrogen, and potassium, by enlarging roots and increasing water efficiency (S. M. Yahaya et al., 2023). This symbiosis also stimulates aquaporin expression, facilitating bidirectional water flow and nutrient transport within the plant (M. Bitterlich et al., 2018; Carbajal and Balesta, 2014).

Phytohormones, such as auxin, cytokinin, gibberellins, and abscisic acid, also regulate plant growth and development (Agboola et al., 2014). AMF enhances hormonal balance, improving root health and overall plant productivity (Marleen Vanstraelen and Eva Benková, 2012). Specific signaling molecules like strigolactones in the rhizosphere further promote root growth and interaction with beneficial microbes (R. T. Kapoor et al., 2024).

Gene Expression and AMF Colonization

Genes like D27, CCD7, CCD8, and MAX1 regulate strigolactone biosynthesis and play an essential role in AMF symbiosis (Yanyan Yu et al., 2022). Additionally, microRNAs (miRNAs) regulate plant - AMF interactions by controlling gene expression at the post - transcriptional

level. These miRNAs influence root structure, growth, and fungal colonization, particularly in sweet potato (Xu Ma et al., 2022). Reduced auxin receptor expression can limit arbuscular growth, underscoring the importance of these molecular interactions in plant development. Thus, AMF symbiosis significantly improves the physiological, molecular, and hormonal processes in storage root crops, enhancing water and nutrient uptake, root health, and overall plant growth.

Application of AMF for Yield Improvement

Root Staining:

Random root samples were carefully selected, washed thoroughly with water, and cut into 1 cm segments. These root segments were treated with KOH or sodium hypochlorite to enhance transparency and then placed in a water bath at 80°C for 20 minutes. The roots were subsequently stained with cotton blue dye and observed under a microscope and confocal microscopy to examine fungal growth within the root tissues (Zicheng Peng et al., 2024). The attachment of fungi to roots varies depending on the crop type and root morphology (Figure 2). As different plants have unique root characteristics, AMF inoculation protocols are often optimized to enhance fungal spore implementation and colonization.

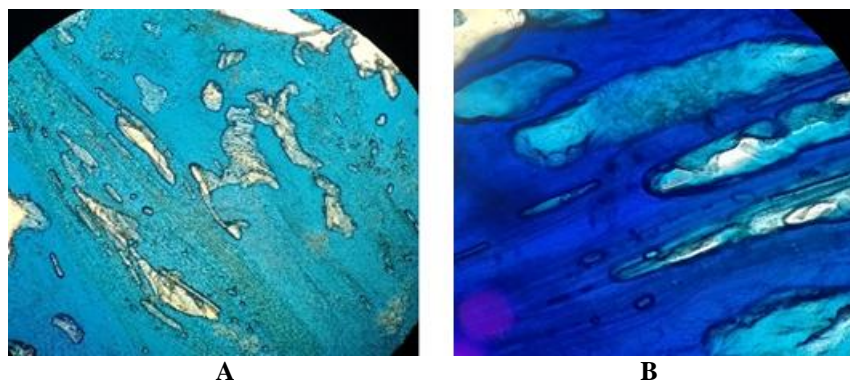


Figure 2: Sweet potato roots treated with AMF: A) Control roots, B) Roots treated with AMF, showing black spots, indicating the presence of AMF in the roots of sweet potato (Havrilla et al.2020).

2. Conclusion

A pot culture experiment was conducted to study root colonization in in - vitro - raised sweet potato plants and to evaluate the effect of Arbuscular Mycorrhizal Fungi (AMF). Observations were made on root colonization, fungal population dynamics, microbial activity in the soil, and the physiological, biochemical, and growth parameters of plants over 25 days.

Results showed that AMF colonization occurred in minor amounts in the roots of in - vitro - raised plants 25 days post - inoculation with a mixture of soil and cow dung. The treatment group achieved a 70% AMF colonization rate, while the control group (without AMF treatment) showed no such colonization.

Key physiological differences between treated and control plants were observed:

- **Greenness Index:** The treated plants showed an increase in the greenness index (scale 5), compared to the control group (scale 3).
- **Plant Length:** The treated plants exhibited an average increase in height of 10 cm compared to the controls.
- **Root Growth:** The roots of treated plants displayed an increase in growth by approximately 10 cm.

AMF inoculation significantly enhanced the physiological and growth parameters of the plants, helping maintain a balance in their physiological behavior and improving overall yield potential.

Abbreviation

AMF: Arbuscular Mycorrhizal Fungi

CCD7: Carotenoid Cleavage Dioxygenase 7

CD8: Carotenoid Cleavage Dioxygenase 8

D27: DWARF27

KOH: Potassium Hydroxide

MAX1: More Axillary Growth 1

Conflict Of Interest

The authors report no financial or any other conflicts of interest in this work

Consent For Publication

All authors agreed and gave their consent for publication.

Author's Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published, and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Journal of Science and Research (IJSR) requirements/guidelines.

Ethical Approvals

This study does not involve experiments on animals or human subjects.

Data Availability

Not Applicable.

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