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Arbuscular Mycorrhizal Fungi (AMF) as Plant Bio-Stimulants for Green Growth

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***Abstract*—One of the most prevalent symbiotic relationships between fungi and the roots of higher plants is arbuscular mycorrhizae. The most prevalent kind of mycorrhizal relationship created by Glomerales fungi are endomycorrhizal associations, also known as vesicular arbuscular mycorrhiza or arbuscular mycorrhiza. By improving the supply and availability of nutrients to plants, mycorrhizal fungus acting as biofertilizers increase crop plant output. They are also known to generate organic compounds, such as phosphatases, and may function as bio-stimulants. Thus, using arbuscular mycorrhiza to develop plants is sustainable and environmentally benign, resulting in green growth. Although these bio-stimulants and biofertilizers are good for plants, their potential as organic fertilisers are limited because they are obligate biotrophs and are hard to cultivate, even axenically. Given their advantageous coevolution with higher plants, the formation of an extensive inoculum of arbuscular mycorrhizal fungi is essential to accelerate green growth. The yields of rice and maize varieties in the sub-Saharan region have significantly increased as a result of several attempts to boost their supply, such as crop rotation and their inclusion with other organic fertilisers. The findings are encouraging since raising yields in dry areas can help residents' nutritional condition and alleviate the hunger and malnutrition that are common there. Large-scale culture and production using bioreactors is a new technique that needs more study and use to produce consistent results. With more availability of arbuscular mycorrhizal fungi, they can definitely surpass all other bio-stimulants in green growth.**

***Index Terms*—Bioreactors, Coevolution Geen growth, Arbuscular Mycorrhiza.**

I. INTRODUCTION

Plant bio-stimulants are defined as chemicals or microbes that are administered to plants to improve their abiotic stress tolerance, crop quality attributes, and/or nutrition efficiency (du Jardin, 2015). Arbuscular mycorrhizal fungi (AMF) are one of the key plants' bio-stimulants (De Pascale et al., 2017). Nearly 80% of vascular plants have a symbiotic relationship with specialised root fungi, which are typically ectomycorrhizal fungi (EMF) and arbuscular mycorrhizal fungi (AMF) (Singavarapu et al., 2024). These fungi exchange carbon for vital nutrients like nitrogen and phosphorus, respectively (Moora, 2014; Brundrett and Tedersoo, 2018).

One of the most crucial aspects of an ecosystem is the mycorrhizal fungus's ability to absorb nutrients from the surroundings (Martin et al., 2017). Since the plant gives the mycorrhizal fungus living in the roots of the plant, carbon, the relationship is recognised to be advantageous to both parties. It has been discovered that fungi help plants by providing them with nutrients from the soil, boosting their resilience to abiotic stress and diseases, and serving as a mediator between other plants and soil bacteria (Smith and Read, 2008). It is also one of the instances of common coevolution of fungi and host (vascular plants) that is distinguished by host and fungal specialisation (Hoeksema et al., 2010). There are different categories of mycorrhiza based on the structural interaction between fungi and plants namely, Ectomycorrhiza, endomycorrhiza, and ectendomycorrhiza.

Ectomycorrhiza fungi (EcM): This group of fungus includes members of the groups Gastromycetes, Homobasidiomycetes, and some Ascomycetes. They are known to settle among forest trees, primarily in the boreal and temperate zones. This particular mycorrhizal group aids in the soil's assimilation of nitrogen. According to Tedersoo and Bahram (2019), these fungi are known to cover the finest feeder roots, which are made of huge woody roots and often develop up towards the soil surface. They do this by forming a mycelial sheath known as a "mantle." Their hyphae form a "Hartig net" that facilitates the movement of nutrients and carbon (C) between the partners by growing closely between the cortical or epidermal cells of the first and second-order feeder roots (Tedersoo and Bahram, 2019).

Endomycorrhiza fungi (EMF): Members of the Glomales (Glomerales) generate these mycorrhizal relationships, which are the most prevalent type of mycorrhiza (Smith and Read, 2008, Brundrett, 2009). Originally used to refer to symbiotic relationships that were produced by all fungi in the order Glomales, the name VAM (vesicular arbuscular mycorrhiza) is now used because a significant suborder of this group does not have the capacity to form vesicles in roots. The members of this group have not been cultivated in axenic culture, separate from their host plants, and form mycorrhiza with agricultural plants. As a result, they are thought to be entirely reliant on plants for their energy and carbon. They are biotrophs by necessity (Kehri et al., 2018).

The new monophyletic phylum Glomeromycota was created by Schüßler et al. (2001) after excluding AM fungi from the polyphyletic Zygomycota. It was believed that this phylum originated from the same ancestor as Ascomycota and Basidiomycota (Schüßler et al., 2001) (Figure 1). Molecular examination of the gene encoding the small subunit ribosomal RNA sequence and morphological and biochemical studies of the fungi provide strong support for this. The fungi form characteristic intracellular structures called as 'arbuscules'.

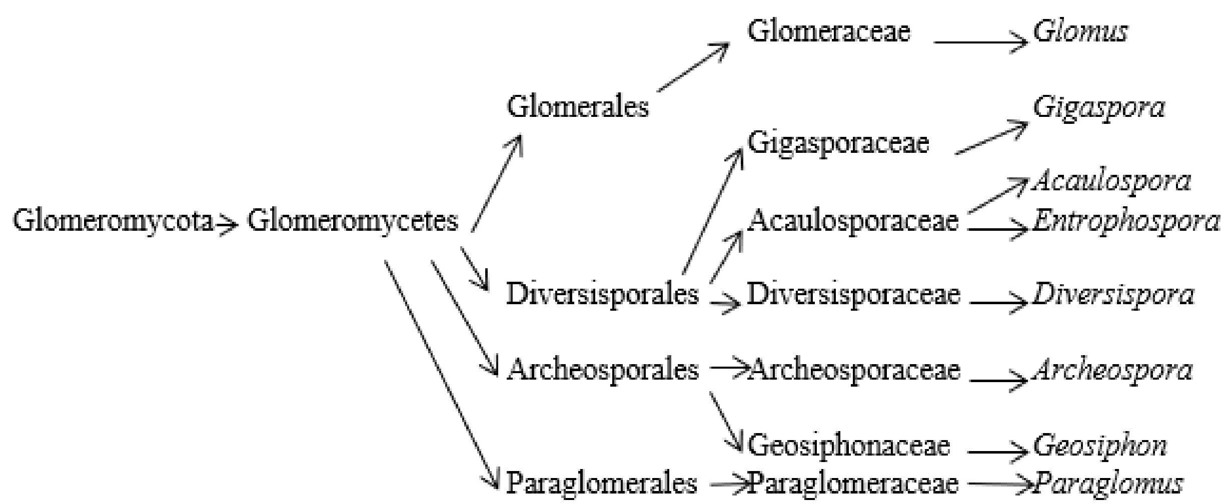

Figure 1: Classification of AM fungi (Schüßler et al., 2001)

Ectendomycorrhiza: Fungi classified as ectendomycorrhiza are members of the genus Wilcoxina belonging to Ascomycetes. Fungi are observed to be primarily associated with pines, spruces, and larch (gymnosperms). It is beneficial for the uptake of mineral nutrients from the soil, just like other mycorrhizal relationships.

Mycorrhiza are commonly formed in plants (Malloch et al., 1980), although their location inside plants varies (Diao et al., 2023). Four common varieties of mycorrhiza are described as follows: Arbuscular mycorrhiza (72% of the total), Ectomycorrhiza (2% of the total), Ericoid mycorrhiza (1.4% of the total), and Orchid mycorrhiza (10% of the total) (Genre et al., 2020; Brundrett and Tedersoo, 2018; Tederesoo and Bahram, 2018).

II. ARBUSCULAR MYCORRHIZA AS BIO-STIMULANTS

According to a meta-analysis, there are no general differences across mycorrhizal species, however overall mycorrhizal benefits to plant development are doubled under Phosphorus constraint as opposed to low-Nitrogen conditions (Hoeksema et al., 2010). According to Antunes et al. (2012), arbuscular mycorrhizal fungi (AMF) can function as bioprotectants, bioregulators, and biofertilizers. Adopting favourable farming techniques can maximise the benefits of AMF (Rouphael et al., 2015). By increasing nutrient absorption, AMF can enhance plant mineral nutrition (Smith and Read, 2008). Their potential as bio-stimulants is supported by number of evidences:

1. Due to interactions with soil bivalent and trivalent cations such as Ca^{2+}, Fe^{3+}, and Al^{3+}, AMF symbiosis significantly increases the uptake of relatively immobile and insoluble phosphate ions in soil (Tinker and Nye, 2000, Fitter et al., 2011).
2. In order to occupy a larger soil volume for nutrient uptake, AMF can create a network of external hyphae that can extend the surface area up to forty times (Giovannetti et al., 2001).
3. Enzymes or organic materials are secreted by AMF (Marschner, 1998). To hydrolyse phosphate from organic substances, they release phosphatases (Koide and Kabir, 2000, Marschner, 2012). For crops cultivated in low-input environments, such as with phosphate shortage, these secretions are advantageous (Smith et al., 2011).
4. In order to acquire ammonia, immobile micronutrients like Cu and Zn, and other soil-derived mineral cations like K^{+}, Ca^{2+}, Mg^{2+}, and Fe^{3+}, AMF produces hyphae, which are crucial (Clark and Zeto, 2000, Smith and Read, 2008).
5. AMF has the ability to alter how plants produce secondary metabolites. These substances (neutraceuticals) may have health-promoting qualities (Sbrana et al., 2014).
6. According to Rouphael et al. (2015), AMF gives agricultural plants the ability to withstand stress.

III. APPROACHES FOR USING ARBUSCULAR MYCORRHIZAE FOR GREEN GROWTH

One of the most significant factors influencing survival in the global ecosystem is the symbiotic relationship between vascular plants and a particular class of fungi termed as mycorrhiza. The most prevalent kind of mycorrhizal relationship created by Glomerales are endomycorrhizal associations, also known as vesicular arbuscular mycorrhiza or arbuscular mycorrhiza. It is hypothesised that members of the Glomeromycota and Endogonomycetes evolved arbuscular mycorrhiza in early land plants. It is believed that arbuscular mycorrhizal fungi are among the significant bio-stimulants of plants. Plants benefit greatly from arbuscular mycorrhizal fungus.

Numerous approaches can take use of the symbiotic relationship between fungi and plants to promote sustained green development. The following highlights a few of these important strategies:

Sustainable horticulture may result from the co-inoculation of beneficial fungus (such as Trichoderma spp.) and other microorganisms, such as bacteria, such as plant growth promoting rhizobacteria (PGPR), with AMF (Xiang et al., 2012, Nadeem et al., 2014, Colla et al., 2015).

When used in conjunction with beneficial agricultural techniques like crop rotation and organic fertilisers, AMF has the potential to replace a wide variety of horticultural inputs (Rouphael et al., 2015). Because AMF has so many advantages for crop plants, studies on how cultural practices affect AMF, particularly in sub-Saharan Africa, have been conducted (Pyret-Guzzon, 2016; Gnamkoulamba et al., 2018). The yields of rice and maize varieties in the sub-Saharan region have significantly increased as a result of several attempts to boost their supply, such as crop rotation and their inclusion with other organic fertilisers. The findings are encouraging since raising yields in dry areas can help residents' nutritional condition and alleviate the hunger and malnutrition that are common there.

To address the need for AMF spores or inoculum, new techniques must be adopted as the traditional methods of AMF propagation are labour and time dependent. One of the most promising innovations for the large-scale cultivation and propagation of AMF propagules is the use of bioreactors (Menge, 2023). Stirred tank reactors, airlift reactors, and packed bed reactors are among the different kinds of bioreactors used for AMF proliferation (Dubey et al., 2013). Other techniques for producing AMF inoculum on a wide scale include the use of phytohormones and synthetic substrates for AMF cultivation (see Menge, 2023). These advances require additional study for efficient AMF inoculum production essential for green growth. Large-scale culture and production using bioreactors is a new technique that needs more study and use to produce consistent results. When arbuscular mycorrhizal fungi are more readily available, they can definitely surpass all other bio-stimulants in green growth.

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