Impact and ~~potentials~~ Potentials of Vesicular-Arbuscular ~~mycorrhizae~~ Mycorrhizae (VAM) ~~f~~Fungi in ~~plant~~ Plant ~~nutrient~~ Nutrient and ~~growth~~Growth: A Sustainable ~~a~~Approach

Abstract

Vesicular-arbuscular mycorrhizae (VAM) also referred to as arbuscular mycorrhizae (AM) is a type of mycorrhizal association between plant roots and fungi. The fungi of VAM species colonize roots of almost all crop plants. They form an intricate network of hyphae (thread-like structures) that are capable of extending far beyond the root system of the plant, greatly increasing the root surface area for nutrient exchange. They form vesicles (round structures filled with lipids) and arbuscules (branched structures that facilitate nutrient transport) in the roots, which act as nutrient exchange sites for the plant and fungus. In India, VAM have huge significance in agricultural systems. They promote plant growth, by facilitating the absorption of water and nutrients from the soil, improving soil structure, and reducing plant disease incidence. VAM are particularly useful in marginal soils, which are deficient in nutrients. They help in enhancing agricultural yield and quality of crops, thereby promoting food security in the country.

VAM fungi play a vital role in improving the nutrient quality in the plants, increasing the plants' growth, helping protect plants against the pathogen, and helps in protecting them from salinity and drought. The majority of terrestrial plants are linked with vesicular-arbuscular mycorrhiza fungus. Their functions range from stress reduction to bioremediation in heavy metal-polluted soils. Heavy metal deposition in plants is a serious environmental issue that is rapidly worsening. HMs like mercury, lead, *etc.* are known toxic elements that have a negative impact on a plant's morpho-physiological and biological characteristics. The current paper focuses on heavy metal absorption, accumulation, and the role of arbuscular mycorrhizal fungi in alleviating heavy metal stress in plants. Arbuscular mycorrhizal (AM) fungi are important soil microbial resources that assist host plants in dealing with a variety of abiotic stresses. The current review gives up-to-date information about AMF responses to abiotic stress. The significance of mycorrhiza against pathogenic populations is well documented, and the advantages of these relationships have been proven to minimize root system vulnerabilities by minimizing abiotic stresses, as well as boosting plant variety's ecological fitness in the soil environment. This review paper represents lipids as essential nutrients for AMF. This paper gives an overview of AM fungi's potential as bio-

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protection agents against soil-borne diseases and discuss about Modes of mycorrhizae-mediated disease control.

Keywords: Mycorrhiza fungus, VAM, Bio fertilizer, Arbuscular Mycorrhiza, Heavy Metal Stress

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Introduction

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The term mycorrhiza comes from the Greek words for "fungus" and "root" and describes many diverse root-fungus associations. Mycorrhizas are found in many environments and their ecological success reflects a high degree of diversity in the genetic and physiological abilities of the fungal endophytes. About 6000 species in the Glomeromycotina, Ascomycotina, and Basidiomycotina have been recorded as mycorrhizal, and the advent of molecular techniques is increasing this number. The taxonomic position of the plant and fungal partners defines the types of mycorrhiza, for which the main distinction is between endo mycorrhizas and ecto mycorrhizas.

~~mycorrhizas.~~

VAM, also called Vesicular arbuscular mycorrhizae, is a fungus in a symbiotic relationship with the roots of plants [1]. Vesicular-arbuscular mycorrhizae's role in improving crop plants is well authenticated [2]. VAM fungi play a vital role in improving the nutrient quality in the plants, increasing the plants' growth, helping protect plants against the pathogen, and helps in protecting them from salinity and drought [3]. There are two types of mycorrhizae which are called ectomycorrhizas and endomycorrhizas. The ectomycorrhizas are defined as extracellular fungal growth inside the root cortex. They are commonly present in temperate and boreal forest trees, and there are over 5000 species within the basidiomycetes [4]. VAM is widely present in almost all natural soils and has also been considered keystone taxa in soil microbial communities [5]. The arbuscular mycorrhizal fungi (AMF) are classified under the taxonomic order Glomales, which at present has six genera. Because they have significant agricultural benefits and are the most prevalent underground symbiosis. The vast diversity of VAM is highlighted by Kilronomos and Kendrick's (1993) claim that "we may know less about mycorrhizas than we assume since we have continuously based general ideas and conclusions on the research of a tiny number of taxa." They are typically found in the roots of angiosperms, gymnosperms, and pteridophytes but can be found in various settings.

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Additionally, they can be found in the gametophytes of various lycopods, Psilotales, and mosses, all of which lack roots [6, 7]. Some plants, however, are mycorrhiza free, such as Proteaceae [8,9]. Cruciferae, Zygophyllaceae [10]. Dipterocaceae, Betulaceae, Myrtaceae and Fagacaeae [8]. Although the exact cause of some plants' failure to develop mycorrhizas is unclear, it may be related to the presence of fungi toxic substances in cortical root tissue or root exudates. It could also be brought on by interactions between the fungus and the plant at the level of the intermediate lamella or the cell wall [11]. Salicylic acid has been proven to inhibit mycorrhization at high dosages [12]. The mycorrhizal infection has been demonstrated in specific field research to boost plant growth and survival, although many reports have little or even adverse effects [13]. Sondergaard and Lindegaard were the first to report mycorrhizas in aquatic plants (1977). And Since aquatic macrophytes colonized lakes and streams have been found to have mycorrhiza [14]. The existence of VAM in freshwater wetlands suggests that the biology and ecology of this interaction warrant additional study, particularly about the function of fungi in plant nutrition and environmental conditions tolerance [15].

What does mycorrhiza do?

It helps /works as root extensions to plant roots, almost 700 times, so there is more access to water and nutrients. It releases enzymes that helps to unlock and dissolve the essential nutrients within the soil. These enzymes makes the nutrients more bio-available (Ready to be taken by plants). Since 1987, information has become available for 221 sedge species, of which 88 (40%) are mycorrhizal, 24 (11%) are facultatively mycorrhizal and 109 (49%) are non-mycorrhizal. There is a considerable increase in the percentage of mycorrhizal species (from 11% to 40%) and a decline in non-mycorrhizal species (from 74% to 49%) since 1987. Mycorrhizal association can either be restricted to a short period during the growing season (Meney *et al.* 1993) or it may be found throughout the growing season (Anwar and Jalaluddin 1994; Muthukumar 1996).

As mycorrhizae helps plants to better utilize nutrients for growth and photosynthesis above-ground, the plants send sugars back down to their roots to nourish the fungi.

- Promotes larger plant growth and healthier, deeper dark green foliage.
- Leads to greater flower and fruit production (more and/or larger). For farmers, higher yields also means higher income.
- Enhanced resilience to stress, heat, and other environmental changes.

- Improved water uptake, leading to increased drought-resistance and less water demand for the plant.
- Lessens the risk of transplant shock, such as when planting new trees or moving indoor-raised seedlings outside.
- Increases plant disease resistance by promoting overall improved plant health. Also, when plant roots are colonized or coated with mycorrhizal fungi, it limits access to the roots by other harmful pests, fungi, or diseases.
- Reduces the need for fertilizer inputs (and associated costs).
- Decreases the accumulation and residual levels of toxic contaminants in crops, such as persistent organic pollutants (POPs), which plants typically readily absorb in their roots and tissues.
- Naturally improves soil structure, fertility, and promotes a healthy living soil food web.

Application of Mycorrhiza in Agriculture:

The application of mycorrhizal fungi in agriculture has gained considerable attention in recent years due to its potential benefits for sustainable agriculture practices. Mycorrhizal inoculants are commercially available and can be used to inoculate seeds or plant roots during transplantation. The use of mycorrhizal inoculants has been shown to improve crop yields, reduce the use of chemical fertilizers and pesticides, and enhance plant tolerance to various environmental stresses. Mycorrhizal inoculants can be used in various cropping systems, including monoculture, intercropping, and ~~agroforestry~~agro forestry. In intercropping systems, mycorrhizal fungi can improve nutrient and water uptake by different crops, leading to higher yields and reduced competition for resources. In ~~agroforestry~~agro forestry systems, mycorrhizal fungi can enhance the growth of trees and understory crops, leading to improved soil health and ecosystem services.

Benefits of Mycorrhizal Bio fertilizer

Mycorrhiza plays a very important role on enhancing the plant growth and yield due to an increase supply of phosphorus to the host plant. Mycorrhizal plants can absorb and accumulate several times more phosphate from the soil or solution than non–mycorrhizal plants. Plants inoculated with endo mycorrhiza have been shown to be more resistant to some root diseases.

Mycorrhiza increase root surface area for water and nutrients uptake. The use of mycorrhizal ~~biofertilizer~~biofertilizers helps to improve higher branching of plant roots, and the mycorrhizal hyphae grow from theroot to soil enabling the plant roots to contact with wider area of soil surface, hence, increasing the absorbing area for water and nutrients absorption of the plant root system. Therefore, plants with mycorrhizal association will have higher efficiency for nutrients absorption, such as nitrogen, phosphorus, potassium, calcium, magnesium, zinc, and copper; and also increase plant resistance to drought. Benefits of mycorrhizal ~~biofertilize~~biofertilizers can be seemed as follows:

1. Allow plants to take up nutrients in unavailable forms or nutrients that are fixed to the soil. Some plant nutrients, especially phosphorus, are elements that dissolve were in water in neutral soil. In the extreme acidic or basic soil, phosphorus is usually bound to iron, ~~aluminum~~aluminium, calcium, or magnesium, leading to water insolubility, which is not useful for plants. Mycorrhiza plays an important role in phosphorus absorption for plant via cell wall of mycorrhiza to the cell wall of plant root. In addition, mycorrhiza help to absorb other organic substances that are not fully soluble for plants to use, and alsohelp to absorb and dissolve other nutrients for plants by storage in the root it is associated with.

2. Enhance plant growth, improve crop yield, and increase income for the farmers. Arising from improved water and essential nutrients absorption for plant growth by mycorrhiza, it leads to improvement in plant photosynthesis, nutrients translocation, and plant metabolism processes. Therefore, the plant has better growth and yield, reduce the use of chemical fertilizer, sometimes up to half of the suggested amount, which in turn increases income for the farmers. As in the trial involving mycorrhizal ~~biofertilizer~~biofertilizers on asparagus it was observed that, when the farmers used suggested amount chemical fertilizer together with mycorrhizal ~~biofertilizer~~biofertilizers, it was found that the crop yield improved by more than 50%, and the farmers' income increased 61% higher than when chemical fertilizer alone was used.

3. Improve plant resistance to root rot and collar rot diseases. Mycorrhizal association in plant roots will help plant to resist root rot and collar rot diseases caused by other fungi.

4. It can be used together with other agricultural chemicals. Mycorrhiza are endurable to several chemical substances; for example; pesticide such as endrin, chlordane, methyl parathion, methomyl carbofuran; herbicide such as glyphosate, fuazifopbutyl; chemical agents for plant disease eliminationsuch as captan, benomyl, maneb triforine, mancozed and zineb.

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Arbuscular Mycorrhizal Fungi as Potential Agents ~~Helping~~helping reduce Heavy Metal Stress in Plants.

Any element with metallic characteristics, a high density, and toxicity at even low concentrations is referred to as a "heavy metal" [16]. By interfering with the activity of nutrients necessary for plant growth, negatively affecting plant shape and physiology, and negatively affecting the proliferation of soil microorganisms and other processes, HMs damage plant growth and productivity [17, 18]. Most of the HMs on the soil surface is naturally occurring; however, when these metals are added in excess amounts to the surrounding atmosphere, the situation worsens [19]. In a natural environment, plants often interact with various microorganisms in the rhizosphere and forge cooperative relationships with them. Beneficial fungi that resemble arbuscular mycorrhizal fungi (VAM) form a symbiotic relationship with plant roots, receiving photosynthetic products produced by the plant in exchange for assistance from the plant in the form of improved photosynthesis, nutrient uptake, protection from HM toxicity, and biomass accumulation [20,21]. Due to its capacity to detoxify HM-induced stress, AMF is considered one of the most critical biological strategies for promoting plant growth and shoot biomass. By HM immobilization in fungal structure, precipitation and chelation in the rhizosphere, sequestration in vacuoles, and activation of antioxidant mechanisms in plants, AMF lowers the stress caused by HM [22].

The HMs ~~are~~is generally present in the soil, but due to human activities that harm both plants and people, their concentrations increase in the environment. They can move between soil-plant systems and are routinely introduced to the soil through various agricultural practices, including agrochemicals. In addition to the natural weathering process, there are other sources of HMs in the soil, including factory chimney emissions, excessive phosphate fertilizer use, additives in gasoline and pigments, pesticides, metal-polluted water, and battery discharge [~~23,24,25,26,27,28,29~~,30,31].

The application of AMF is an environmentally benign technique and a valuable component for achieving sustained production by increasing soil health and protecting plants from abiotic and biotic challenges [32].

Arbuscular Mycorrhizal Fungal Responses to Abiotic Stres~~s~~

Arbuscular mycorrhizal (AM) fungi belonging to the subphylum Glomeromycotina may develop mutualistic symbiotic connections with more than 80% of terrestrial plant species

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[33,34]. AM fungi also undergo a variety of modifications to adapt to abiotic stress. AM fungi's adaptability to stressful circumstances is primarily expressed by numerous distinct elements, including colonization, arbuscular development, spore germination, and sporulation. The hyphal membrane of AM fungus comprises phospholipids (PLs), whereas spores are mostly made up of neutral lipids [35]. Several studies have proven abiotic stress to have a deleterious impact on mycorrhizal colonization. Salinity alkalinity stress dramatically reduces the number of entrance sites on roots and vesicles inside sources [36]. With increased salinity, mycorrhizal frequency (F%) and intensity (M%) decline dramatically [37]. Arbuscules are the primary locations for food exchange between two symbiotic individuals and are regarded as the fundamental structures of AM symbiosis [38,39]. Arbuscules have a life span and functional lifespan of just 7.5-8.5 and 2-3 days, respectively [40,41]. The authors divided arbuscule development into five phases. They revealed that fewer juvenile arbuscules matured entirely, but adult arbuscules were promoted to become senescent and collapse in response to low-pH or acidic soil conditions [42]. Increased phosphate supply for PL production (Wewer *et al.*, 2014).

Feng *et al.* (2020) recently found a substantial drop in AM fungal PLs and an accumulation of NLs in colonized roots under low-pH stress (pH 4.5 vs. 6.5), indicating the interconversion of lipid fractions in AM fungus in response to abiotic stress [43].

Lipids as Essential Nutrients for Arbuscular Mycorrhizal Fungi in Reaction to Abiotic Stress

Lipids are the most prevalent substances in AM fungus; these lipids mainly consist of PLs and NLs, although other lipids are present in trace amounts [44,35,45]. Further_more, AM fungi do not manufacture lipids from scratch but rather obtain them from their hosts, emphasizing the importance of lipids as critical nutrients in AM symbiosis [46].

VAM as a bio-control agent for disease management

There is a rising global awareness of the harmful consequences of the indiscriminate use of chemical pesticides, which are dangerous to human life and pollute the environment and ecosystems. Long-term usage of broad-ranging chemical pesticides has been detected as one of the primary drivers of environmental contamination, contributing to the deterioration of agricultural land and the entire ecosystem. The magnitude of the problem can be reduced or prevented by utilizing chemicals in conjunction with biological, physical, and cultural control techniques in integrated pest and disease improvement initiatives [47]. Mycorrhizal fungi are

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inhabitants of the fungus kingdom and are an essential component of agricultural and natural resources. The structures and functions of mycorrhizal fungi association vary greatly, but the Arbuscular Mycorrhizae (AM) is the most common interaction [48].

VAM has been shown to increase plant tolerance to infections without causing significant output losses and, in certain circumstances, to increase pathogen inoculation density. This adjustment appears to be connected to improved photosynthetic ability [49,50]. As established by Hwang, the effectiveness and efficiency of AMF in boosting plant development allows mycorrhizal plants to withstand infections [51]. Plant tolerance to pathogens can occur according to the AMF species and their capacity to improve host nutrition and development, even though inefficient AMF species reduce many ~~Pathogen~~ pathogen entrances by triggering a plant defensive response [52]. Mycorrhizal plants may tolerate pathogens, which can mitigate root damage and photosynthate depletion caused by pathogens [53,54]. Although it is widely assumed that AMF interacts equally with host plants, AMF prefers one host or host cultivar over another [55]. The involvement or lack of interaction between naturally existing AMF and diseases in the field is most likely determined by the dispersion of the organisms, particularly under various crop alternations. In wheat, it has also been shown to significantly reduce disease severity due to AMF colonization and increased P absorption, followed by changes in root exudation patterns [56,57].

Modes of ~~mycorrhizae~~Mycorrhizae-mediated disease control

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Conclusion

Recent studies on Vesicular-Arbuscular Mycorrhizae (VAM) have shown that they can be beneficial to plants by improving their nutrient uptake and overall health. In India, VAM has been found to be especially helpful for crops such as soybeans, cotton, and wheat. It has been seen that the use of VAM can reduce the need for additional fertilizers and pesticides, thus improving soil health and reducing costs for farmers. With ~~ongoing~~ongoing research and advancements, it is hoped that VAM can aid in sustainable agriculture practices in India.

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