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Mycorrhiza, Bacteria and Plant an Organized Model of Rhizoshere Interaction

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Running title: Microorganism and plants a model of rhizoshere interaction

Abstract: The first step to analyze and understand plant growth and development is to understand the environmental factors that can modulate it. The rhizoshere soil is a rich environment of interaction between plants and soil organisms that may enhance its growth and production. Plant's roots, mycorrhiza, and bacteria are three elements of rhizoshere soil interaction. Plant's root exudates encourage mycorrhiza to colonize with the root system internally or externally. The roots secretions, provide some nutrients, and are considered as recognition signals to host mycorrhiza in species- specific manner, whereas mycorrhiza secretes other compounds to attract bacteria. Bacteria produce several compounds that increase mycorrhiza production and formation which benefit the plants indirectly by mediating mycorrhiza exudates and directly by changing soil characteristics. The bacteria that help mycorrhiza are called mycorrhiza helper bacteria (MHB). The interaction between mycorrhiza, bacteria, and plant's roots creates symbioses that influence rhizoshere soil. The changes induced by chemical fertilizer are harmful to the environment and soil microflora, despite the benefit for plant production. Changing soil characteristics such as pH, water, and elements availability, through the use of mycorrhiza and bacteria, combination as biofertilizer is an environmentally safe approach. Using biofertilizer designed to specific plant growth, can improve plant production and tolerance especially in poor or contaminated soil.

Key words: Mycorrhiza, Bacteria, rhizoshere interaction, biofertilizer, symbioses

1. INTRODUCTION

Rhizoshere is the layer of soil surrounding the plant's roots, where most of microorganisms' interactions occur. The rhizoshere is considered as the hot spot for soil where major interactions occur. The rhizoshere interaction is controlled by three elements: plant roots, mycorrhiza, and bacteria are (Fig.1). The plant's roots secrete organic compound as a result of photosynthesis and other plant processes [1] that attract mycorrhiza and bacteria, and change the rhizosphere community and dynamics. The active components of rhizoshere, mycorrhiza, and bacteria have been used in several studies, solely or in combination to increase plants production or tolerance [2-5].

Mycorrhiza is a fungus known to colonize and form spores within a plant's roots, either by intracellular association as arbscular mycorrhiza (AM) or endomycorrhiza or extracellular association as ectomycorrhiza (Fig.2). Studies have indicated that the interaction between plants and mycorrhiza, caused by chemical compounds produced, either by the plants or the mycorrhiza and mediated by bacteria [6, 7]. The mycorrhizal symbiosis within plants roots affects the microorganisms' population in the rhizoshere which, cause changes in the soil characters such as pH, nutrients availability, and water stable soil aggregates [3]. The rhizoshere changes, due to microorganisms' interaction, affect a plant's health and further development. Mycorrhiza colonization is plant species dependant [8] while bacteria diversity in rhizoshere is mycorrhiza dependant [9].

Mycorrhiza can increase or decrease bacteria existence and diversity in rhizosphere [3, 9]. Moreover, mycorrhiza changes elemental, heavy metals availability, and may increase it or block it from the plants [10]. Similar finding in another study, indicated that the endomycorrhiza *G. intraradices*. showed tolerance to heavy metals Cd, Pb, and Zn [11]. These findings encouraged the use of mycorrhiza in phtyoremediation to increase plant's tolerance to heavy metals contaminated soil [12,13]. In many studies, the use of mycorrhiza or bacteria inoculums was limited to previous relation of the inoculums to site, species, or plant's natural habitats. Whereas literature showed that microorganism inoculums used from different sources that are not related to the plant host or site may produce significant growth promoting results [14-16].

Selection of the best inoculums combination of mycorrhiza and bacteria need extensive studies to lead us to efficient use of natural resources such as biofertilizer. The increase in plant tolerance, biomass production, and phytoremediation in contaminated soil could be useful for the production of transgenic plant. The goal of this review is to concentrate on the current knowledge of mycorrhiza and bacteria interaction role in changing rhizoshere and enhance plants growth.

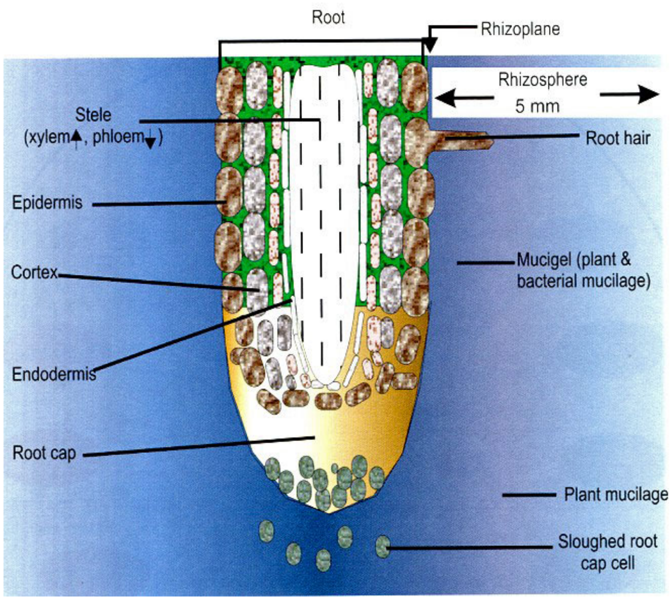

Figure 1: Rhizoshere soil and interaction components [64].

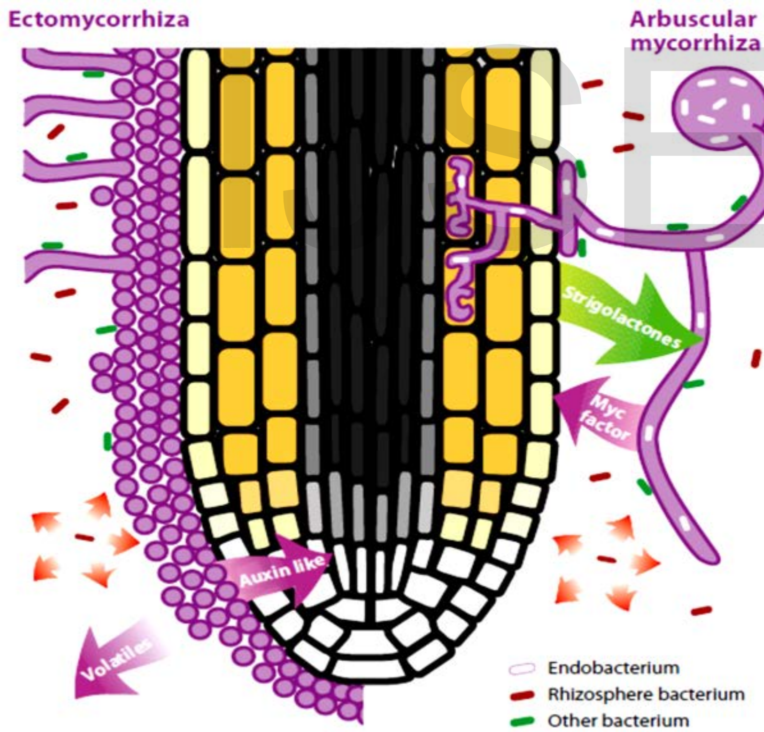

Figure 2: Interaction and existence of organisms in the rhizoshere region; bacteria, endomycorrhiza and ectomycorrhiza [65]

2. HOW DO MYCORRHIZA-PLANTS AND BACTERIA INTERACTIONS CHANGES THE RHIZOSHERE?

2.1. Mycorrhiza

Mycorrhiza produces active organic acids and chelators which may act as phosphate transporters to deliver inorganic phosphate to the plants [17] and to maintain mycorrhiza development [18]. Moreover, mycorrhiza activate nitrogen plant transporter [19-21] and increased Zn-uptake in wheat [66]. Carbon is transferred from the host plant to mycorrhiza in general [21], while in some cases; carbon is transferred from the mycorrhiza to the plant host [22]. The nature of interaction between plants and mycorrhiza starts by root chemical exudates. Some chemical compounds produced by the plant, such as polysaccharide and glycoprotein fibrils known to facilitate mycorrhiza surface attachment to the plant. Other compounds such as phytohormones, phenolic compounds, enzymes, and lectin, play an essential role in plant's-mycorrhiza recognition [23].

2.2 Mycorrhiza helper bacteria

Another factor reported by Duponnois and Garbaye [24] is mycorrhiza helper bacteria MHB, where some bacteria mediate or increase mycorrhiza colonization in the plant's root system or detoxify mycorrhizal accumulated metabolites [2, 54-58]. The MHB can colonize externally on hyphae surface or internally in cytoplasm as endobacteria [8]. The most studied MHB are: Pseudomonas fluorescens BBc6R8 and Bacillus which reported to enhance mycorrhiza formation [24-26]. Some of MHB influence mycorrhiza only by altering its structure [33] or enhance its formation [23-25, 27, 59, 60] or provide carbon source to mycorrhiza in form of malic and citric [2, 24]. Carbon source provided by the MHB has a major role in mycorrhiza bacteria signaling and interaction which then increases the mycorrhiza establishment and production [13].

The bacteria mycorrhiza interaction seems to be mutual and species-specific. In study of Schreiner *et al.* [3] *Glomus etunicatum* soils had the highest gram positive and gram negative populations, while *Glomus mosseae* soils had the lowest counts of gram negative bacteria (*Pseudomonas* populations). This finding was confirmed later by Vesterg˚ard, et al., [9] who reported that bacteria diversity is affected by AM composition. In a study conducted by Rajesh Kannan *et al.*, [13] they found a significant increase of fatty acids such as butyric acid, capric acid, undecanoic acid, lauric acid, tridecanoic acid, myristic acid, cis-10-pentadecanoic acid, behenic acid, arachidonic acid, trichosanoic acid, lignoceric acid, cis [11, 14] eicosadienoic acid, eicosapentaenoic acid, nervonic acid, and docosahexanenoic acid, where associated, when MHB combined with AM in three species of bacteria *Azotobacter* , *Rhizobium* and *Pseudomonas.*

The effect of ectomycorrhiza on a plant's elements uptake is mediated by MHB, where ectomycoorhiza produce hydroxamate siderophore which increase elements availability mediated by MHB siderphore which disturb poor nutrient soil to increase uptake by plants [28, 29, 61]. Other MHB influence both plants and mycorrhiza [8] as phosphate solubilizing bacteria [30, 63]. MHB reported to increase plant's nutrient uptake for some elements as P, Cu, Zn and Fe [31]. The nutrient availability may be induced by bacteria as *Pseudomonas* fluorescens siderophores compounds that change soil pH [32]. The highest alkaline phosphatase activity found to be associated with *Azotobacter, Pseudomonas* and *Rhizobium* when combined with AM, which is essential enzyme to solubilize phosphorous in soil [13].

The rhizospheric bacteria activities include production of auxin (indole-3-acetic acid) by some bacteria that increase root growth [23] and enhance mycorrhizal- plants association [6, 33]. In addition, bacterial enzymes such as endoglucanase, cellobiose hydrolase, pectatelyase, and xylanase, that facilitate fungal penetration to the roots [23] by degrading root cell wall [34].

Another group of bacteria, which live in the root zone, play a key role in rhizosphere processes [21] and benefit plants as associative N2-fixing bacteria [35, 36], plant growth-promoting rhizobacteria [37] antagonists of plant pathogens [38- 40,63] and increase plant drought tolerance [13].

3. USING DIFFERENT RHIZOSHERE COMBINATION TO INCREASE PLANTS GROWTH AND TOLERANCE

In many studies, the use of different mycorrhiza and bacteria in combination or alone, has showed significant results in a plant's biomass and nutrient uptake, in poor soil [12, 36, 41, 54-58]. The use of mycorrhiza solely reported to increase plant biomass, shoot, and root length, water use efficiency for *Allium sativum L.* under drought stress conditions [42]. In addition, shoot biomass and phosphorus uptake increased in *Eucalyptus coccifera* Hook. seedlings growing in P-deficient soil when treated with mycorrhiza [43].

Calliandra (*Calliandra calothyrsus*) seedlings showed significant increase in growth, height, and shoot biomass, when seeds were inoculated with mycorrhiza [41]. Another study showed significant increase in barley (*Hordeum Vulgare*s L.) shoot height, shoot and root biomass when treated with mycorrhiza. The gene expression in the same experiment was also triggered by a significant increase was reported in calcium de-pendent protein kinases (CDPKs), phosphoenol pyrovate carboxylases (PEPCs), and proline-5 carboxylate synthetase (P-5CS) in barley plants [44]. Moreover, more than 500 mycorrhiza-associated transcripts discovered in mycorrhiza colonized roots of tomato plants, including putative zinc, iron, aquaporin, and carbohydrate transporters, as well as mycorrhizal-associated alternative gene splicing [45]. Some ectomycorrhiza was reported to tolerate heavy metals as Cu, Cd, and Zn [46] which extend their capability in soil remediation [10].

Sisaphaithong et al. [47] reported that mycorrhiza induces a significant increase in phosphate transporter genes expression, in the root of sorghum, barley, and wheat. Mycorrhiza affect plant's stomatal conductance, which increase photosynthetic rates [48]. Several studies reported a significant increase in photosynthesis, and P-efficiency use in plants treated with mycorrhiza [49-51].

Some gram positive bacteria, such as *Paenibacillus* sp., strain B2 stimulate mycorrhiza colonization, and has antagonistic activity towards soilborne fungal pathogens [52,62]. Jäderlund *et al.* [5] reported that the interaction between bacteria and arbscular mycorrhiza is very specific, while *Pseudomonas fluorescens* and *G. intraradices* combination increased the winter wheat (*Triticum aestivum* cultivar Tarso) shoot's dry weight but, decrease mycorrhiza roots colonization. The combination between *Paenibacillus brasilensis* and *G. intraradices* caused a decrease in shoot's dry weight but, significant increase in root's mycorrhiza colonization. Whereas, *G. mosseae* colonization increase significantly weather combines with *Pseudomonas fluorescens* or *Paenibacillus brasilensis*. In addition *G. mosseae* inhibit root disease symptoms induced by *M. nivale* fungus [5]. Increase in plant's biomass and development reported when using mycorrhiza and bacteria combination. The use of *K. pneunoniae* bacteria and *Glomus deserticola* mycorrhiza increased the sea oat's (Uniola paniculata L) shoots and root's dry weight, phosphorous concentration and enhance its growth in beach sand [36]. In another study, *Glomus mosseae* increased soybean (*Glycine max* (L.) Merr.) pod dry weights and pod/stem and root/stem ratios but, decrease root lengths, while *Glomus etunicatum* increased stem height, dry weights, and nodes [3]. Rajesh Kannan et al., [13] found that using combination of *Pseudomonas* and AM or *Rhizobium* and AM increased maize shoots and roots weight and length.

Using bacteria treatment solely for plant treatment, showed growth promoting results, thus called, growth promoting bacteria. In a study, *Azotobacter chroococcum and Azospirillum lipoferum* increased plant biomass and seed yield in ajowan (Carum copticum) [53]. Sorghum plants (S. bicolor) growing in Cd contaminated soil, showed significant increase in shoot and total biomass, when treated with fluorescent pseudomonad. In the same study *fluorescent pseudomonad* decrease Cd soil toxicity and increase sorghum tolerance and AM colonisation [12].

3.1 Mycorrhiza symbiosis at the molecular level

The ability of mycorrhiza to promote plants nutrients uptake as phosphate is associated with genes expression, the genes are known to induce phosphate transporter proteins. Studies have identified two genes GvPT and GiPT that are expressed in mycorrhiza [67, 68] encoded five phosphate transporters StPT3, StPT4, ORYsa; Pht1;11 and MtPT4[69-71] which are involved in transferring phosphate form mycorrhiza mycelium to plants root. The symbioses establishment require at least seven genes known as SYM genes [72] some of the genes are nodulation specific as LjNFR1 / LjNFR5 [73]. Moreover, some genes as MtDMI1 and MtDMI2 are involved in calcium influx [74, 75]. Although mycorrhiza involved in triggering plants gene expression and singling pathway through SYM genes associated with colonization [72] more studies needed to understand how the symbiosis promote plants growth and elements uptake.

4. CONCLUSION

Studying rhizoshere different component plant roots, mycorrhiza, and bacteria is essential to get a better understanding of the nature of interaction. Roots exudates changes soil characters and facilitate mycorrhiza plants recognition and association. The mycorrhiza associates externally or internally with plant's roots in species specific manners. The association between plants and mycorrhiza, affect bacteria diversity and population. Bacteria activities exist in rhizoshere promote mycorrhiza or plants, or even both of them. Mycorrhiza and bacteria combination increase the plant's productivity and tolerance, and reduce pathogenic organisms existence in soil. The combination of mycorrhiza and bacteria can be used as biofertilizer in poor soil to increase the plant's survival and element uptake or in contaminated soil to increase plants tolerance to heavy metals. Using mycorrhiza and bacteria as a biofertilizer is a cheap and environment friendly method to increase a plant's productivity in regular soil. Studying the changes at a molecular level with mycorrhiza and bacteria combination that are known to promote plant production may help to produce transgenic plants, with the ability to cope with different environmental stress factors. More studies needed on gene expression associated with plants, mycorrhiza and growth promoting bacteria to understand symbiotic interaction and enable transgenic plants approach.

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