Indigenous Arbuscular Mycorrhizal Performance

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It is difficult to assess the function of indigenous microorganisms interacting with plants in the environment. The function can be evaluated by using mutants of host plants that are unable to express the function. The function of arbuscular mycorrhizal fungi (AMF) in roots can be assessed by using symbiotic mutant of *Lotus japonicus* that do not form arbuscules, which are their nutrient exchange organs.

Keywords: arbuscular mycorrhiza ; mycorrhizal mutant, ; Lotus japonicus, ; indigenous fungi, ; phosphate, ; growth promotion, ; inoculation

1. Introduction

Most plants, including many economically important crops, are usually colonized with arbuscular mycorrhiza fungi (AMF) in the subphylum Glomeromycotina [1] in the fields. AMF colonize roots to obtain carbon sources and develop extraradical hyphae that absorb mineral nutrients from the soil and transfer them to the host plants [2]. AMF that have achieved a symbiosis that is sufficient to amplify their own biomass often form spores in the soils and develop intraradical mycelia with many vesicles, although these hyphal morphologies depend on the AMF type [3][4]. These vegetative and reproductive AMF hyphal structures serve as a source of inoculation for colonizing different plant species in fields, because AMF generally lack strict host specificity; accordingly, the root is often co-colonized with multiple AMF species [5][6].

2. AMF

To investigate the biological properties of each AMF species, many cultured lines have been established by isolating spores and inoculating a single spore in plants in a pot culture or axenic root organ culture [7]; however, they have been generated using only limited species [8]. Inoculation studies of these lines in different plant species, with the exception of modern wheat or barley varieties [9][10], have led to one well-recognized conclusion, i.e., AMF colonization is, in many cases, beneficial for plant nutrition and productivity (see the objective review [11]). Moreover, pot inoculation studies have shown that phosphate (P) uptake by the host plant is often improved and the P concentration in shoots is also increased in the mycorrhized condition compared with the non-mycorrhized condition [3]. This improvement in P uptake led to an expectation that AMF inoculants can be used as bio-fertilizers; i.e., that AMF inoculation in the field may enable farmers to decrease the amount of P fertilizers [12]. For example, inoculation of AMF can substantially reduce P fertilizer application to Welsh onions and lead to the achievement of a marketable yield under field conditions [13]; however, it remains debatable whether mycorrhizal fungi increase the transport of P to plants directly [14]. One way to utilize AM symbiosis in crop cultivation is to increase the propagules of indigenous AMF in the soil. The increased AMF propagules in the soil after the cultivation of host crops can improve the productivity of soybean crops in the following year compared with the former cultivation of non-host crops [15][16][17]. Accordingly, it is expected that P fertilization of the next-year cultivation can be reduced by half [18]. Another approach consists in inoculating the soil with exotic AMF culture lines. As mentioned above, it has been proven that AMF inoculation is useful in many cases, at least in pot tests under well-controlled environmental conditions. However, it is also true that not all inoculation tests provide positive results, even in pot experiments; some plant species clearly show a positive effect of the inoculation of AMF, while others show neutral or even negative effects of the same AMF [19]. The outcome of these mycorrhization approaches is considered to be context dependent [20]; i.e., the type of AMF, plant type, growth condition, growth stage, soil abiotic (nutritional and physical) and biotic (indigenous AMF and soil microbes) properties, etc., affect the performance of mycorrhizas [21][22][23].

Whether the AMF inoculation strategy is effective or not remains a matter of debate [8][11][24]. Usually, the soil contains a large amount of AMF propagules [25][26]. In addition, it has been suggested that indigenous AMF are better adapted to the local edaphic conditions than are exotic AMF and are, thus, better able to promote plant growth [27][28]. In fact, there are few examples of increased crop yields after AMF inoculation in the field [29]. However, it is possible that the performance of indigenous AMF is severely decreased in some soils because of various changes in the soil management history (e.g., excessive tillage, sterilization, and fertilization) [30][31]. Therefore, if the low performance of indigenous AMF could be investigated in advance, the inoculation of exotic AMF could also be effective [32].

To the best of our knowledge, there is no method for evaluating the performance of indigenous AMF. In this study, we developed a method to evaluate the performance of indigenous AMF in promoting plant growth in pot culture. We used a mycorrhizal mutant of *Lotus japonicus*, MG-20, which is a model plant of legumes. The mutant line has a nonsense mutation in the *STR* (*stunted arbuscule*) gene, which encodes an ABC transporter [33]. *STR* is thought to be implicated in lipid transfer from plants to AMF, as assessed using genetic analyses [34][35][36][37]. Recent genome analyses have revealed that AMFs are dependent on plants for lipid synthesis, which is essential for the establishment of symbiosis [38][39]. Thus, in the *str* mutant of *L. japonicus*, *Medicago trucatula*, and rice (*Oryza sativa*), the early root-colonization stage looks normal, but the branching of arbuscules, which are intracellular symbiotic fungal structures that play a central role in mycorrhizal function, is severely inhibited (*stunted arbuscule*: *str*) [33][40][41]. The expression of mycorrhiza-specific P and ammonium transporter genes in the *L. japonicus str* mutant is severely inhibited compared with wild-type (WT) plants [33], suggesting the attenuation of a broad range of mycorrhizal functions in this mutant. From a different perspective, if the growth of WT plants under the presence of AMF is similar to that of *str*, the effect of colonization with indigenous AMF under the assay condition is not expressed (i.e., low performance). Thus, we examined the growth ratios of WT and *str* mycorrhizal mutant using 24 soils. Furthermore, we investigated whether an AMF inoculum was effective in promoting plant growth in soils that were assessed as having low indigenous mycorrhizal performance.

References

1. Joseph W. Spatafora; Ying Chang; Gerald L. Benny; Katy Lazarus; Matthew E. Smith; Mary L. Berbee; Gregory Bonito; Nicolas Corradi; Igor V. Grigoriev; Andrii Gryganskyi; et al. A phylum-level phylogenetic classification of zygomycete fungi based on genome-scale data.. *Mycologia* **2016**, *108*, 1028-1046, 10.3852/16-042.
2. Marcel G. A. Van Der Heijden; Francis Martin; Marc-André Selosse; Ian R. Sanders; Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytologist* **2015**, *205*, 1406-1423, 10.1111/nph.13288.
3. Smith, S.E.; Read, D.J. Mycorrhizal Symbiosis; Academic Press: Cambridge, UK, 2008.
4. Paola Bonfante; Andrea Genre; Mechanisms underlying beneficial plant–fungus interactions in mycorrhizal symbiosis. *Nature Communications* **2010**, *1*, 1-11, 10.1038/ncomms1046.
5. D Van Tuinen; E. Jacquot; B. Zhao; A. Gollotte; V. Gianinazzi-Pearson; Characterization of root colonization profiles by a microcosm community of arbuscular mycorrhizal fungi using 25S rDNA-targeted nested PCR. *Molecular Ecology* **1998**, *7*, 879-887, 10.1046/j.1365-294x.1998.00410.x.
6. Maarja Öpik; M. Metsis; Tim Daniell; Martin Zobel; Mari Moora; Large-scale parallel 454 sequencing reveals host ecological group specificity of arbuscular mycorrhizal fungi in a boreonemoral forest. *New Phytologist* **2009**, *184*, 424-437, 10.1111/j.1469-8137.2009.02920.x.
7. J. André Fortin; Guillaume Bécard; S. Declerck; Yolande Dalpé; Marc St-Arnaud; Andrew P. Coughlan; Yves Piché; Arbuscular mycorrhiza on root-organ cultures. *Canadian Journal of Botany* **2002**, *80*, 1-20, 10.1139/b01-139.
8. Hart, M.M.; Antunes, P.M.; Chaudhary, V.B.; Abbott, L.K. Fungal inoculants in the field: Is the reward greater than the risk? Funct. Ecol. 2018, 32, 126–135.
9. Lehnert, H.; Serfling, A.; Enders, M.; Friedt, W.; Ordon, F. Genetics of mycorrhizal symbiosis in winter wheat (Triticum aestivum). New Phytol. 2017, 215, 779–791.
10. Pasquale De Vita; Luciano Avio; Cristiana Sbrana; Giovanni Laidò; Daniela Marone; Anna M. Mastrangelo; Luigi Cattivelli; Manuela Giovannetti; Genetic markers associated to arbuscular mycorrhizal colonization in durum wheat. *Scientific Reports* **2018**, *8*, 10612, 10.1038/s41598-018-29020-6.
11. Megan H. Ryan; James H. Graham; Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops. *New Phytologist* **2018**, *220*, 1092-1107, 10.1111/nph.15308.
12. Priyanka Srivastava; Bhawna Saxena; Bhoopander Giri; Arbuscular Mycorrhizal Fungi: Green Approach/Technology for Sustainable Agriculture and Environment. *Mycorrhiza - Nutrient Uptake, Biocontrol, Ecorestoration* **2017**, , 355-386, 10.1007/978-3-319-68867-1_20.
13. Keitaro Tawaraya; Ryouta Hirose; Tadao Wagatsuma; Inoculation of arbuscular mycorrhizal fungi can substantially reduce phosphate fertilizer application to Allium fistulosum L. and achieve marketable yield under field condition. *Biology and Fertility of Soils* **2012**, *48*, 839-843, 10.1007/s00374-012-0669-2.

14. Elliott, A.J.; Daniell, T.J.; Cameron, D.D.; Field, K.J. A commercial arbuscular mycorrhizal inoculum increases root colonization across wheat cultivars but does not increase assimilation of mycorrhiza-acquired nutrients. Plants People Planet 2019.
15. Joji Arihara; Toshihiko Karasawa; Effect of previous crops on arbuscular mycorrhizal formation and growth of succeeding maize. *Soil Science and Plant Nutrition* **2000**, *46*, 43-51, 10.1080/00380768.2000.10408760.
16. Karasawa, T. Arbuscular mycorrhizal associations and interactions in temperate cropping systems. Res. Bull. Natl. Agric. Res. Cent. 2004, 179, 1–71.
17. Toshihiko Karasawa; Masako Takebe; Temporal or spatial arrangements of cover crops to promote arbuscular mycorrhizal colonization and P uptake of upland crops grown after nonmycorrhizal crops. *Plant and Soil* **2011**, *353*, 355-366, 10.1007/s11104-011-1036-z.
18. Norikuni Oka; Toshihiko Karasawa; Keiki Okazaki; Masako Takebe; Maintenance of soybean yield with reduced phosphorus application by previous cropping with mycorrhizal plants. *Soil Science and Plant Nutrition* **2010**, *56*, 824-830, 10.1111/j.1747-0765.2010.00518.x.
19. John N. Klironomos; VARIATION IN PLANT RESPONSE TO NATIVE AND EXOTIC ARBUSCULAR MYCORRHIZAL FUNGI. *Ecology* **2003**, *84*, 2292-2301, 10.1890/02-0413.
20. Jason D. Hoeksema; V. Bala Chaudhary; Catherine A. Gehring; Nancy Collins Johnson; Justine Karst; Roger T. Koide; Anne Pringle; Catherine Zabinski; James D. Bever; John C. Moore; et al. A meta-analysis of context-dependency in plant response to inoculation with mycorrhizal fungi. *Ecology Letters* **2010**, *13*, 394-407, 10.1111/j.1461-0248.2009.01430.x.
21. Florian Walder; Marcel G.A. Van Der Heijden; Regulation of resource exchange in the arbuscular mycorrhizal symbiosis. *Nature Plants* **2015**, *1*, 15159, 10.1038/nplants.2015.159.
22. Jeff R. Powell; Matthias C. Rillig; Biodiversity of arbuscular mycorrhizal fungi and ecosystem function. *New Phytologist* **2018**, *220*, 1059-1075, 10.1111/nph.15119.
23. Sébastien Renaut; Rachid Daoud; Jacynthe Masse; Agathe Vialle; Mohamed Hijri; Inoculation with Rhizophagus irregularis Does Not Alter Arbuscular Mycorrhizal Fungal Community Structure within the Roots of Corn, Wheat, and Soybean Crops. *Microorganisms* **2020**, *8*, 83, 10.3390/microorganisms8010083.
24. Matthias C. Rillig; Carlos A. Aguilar-Trigueros; Tessa Camenzind; Timothy Cavagnaro; Florine Degrune; Pierre Hohmann; Daniel R. Lammel; India Mansour; Julien Roy; Marcel G. A. Van Der Heijden; et al. Why farmers should manage the arbuscular mycorrhizal symbiosis. *New Phytologist* **2019**, *222*, 1171-1175, 10.1111/nph.15602.
25. Lekberg, Y.; Koide, R.T. Integrating physiological, community, and evolutionary perspectives on the arbuscular mycorrhizal symbiosis. Can. J. Bot. 2014, 251, 241–251.
26. Kobae, Y. Dynamic phosphate uptake in arbuscular mycorrhizal roots under field conditions. Front. Environ. Sci. 2019, 6, 159.
27. R. Paul Schreiner; Effects of native and nonnative arbuscular mycorrhizal fungi on growth and nutrient uptake of 'Pinot noir' (Vitis vinifera L.) in two soils with contrasting levels of phosphorus. *Applied Soil Ecology* **2007**, *36*, 205-215, 10.1016/j.apsoil.2007.03.002.
28. A. Faye; Y. Dalpé; K. Ndung'u-Magiroi; J. Jefwa; I. Ndoye; M. Diouf; D. Lesueur; Evaluation of commercial arbuscular mycorrhizal inoculants. *Canadian Journal of Plant Science* **2013**, *93*, 1201-1208, 10.4141/cjps2013-326.
29. Alia Rodriguez; Ian R. Sanders; The role of community and population ecology in applying mycorrhizal fungi for improved food security.. *The ISME Journal* **2014**, *9*, 1053-61, 10.1038/ismej.2014.207.
30. M. H. Miller; T. P. Mcgonigle; H. D. Addy; Functional Ecology of Vesicular Arbuscular Mycorrhizas as Influenced by Phosphate Fertilization and Tillage in an Agricultural Ecosystem. *Critical Reviews in Biotechnology* **1995**, *15*, 241-255, 10.3109/07388559509147411.
31. Valeria Faggioli; Marta Noemí Cabello; Gabriel Grilli; Martti Vasar; Fernanda Covacevich; Maarja Öpik; Root colonizing and soil borne communities of arbuscular mycorrhizal fungi differ among soybean fields with contrasting historical land use. *Agriculture, Ecosystems & Environment* **2019**, *269*, 174-182, 10.1016/j.agee.2018.10.002.
32. Lynette K. Abbott; Ad Robson; The role of vesicular arbuscular mycorrhizal fungi in agriculture and the selection of fungi for inoculation. *Australian Journal of Agricultural Research* **1982**, *33*, 389, 10.1071/ar9820389.
33. Tomoko Kojima; Katsuharu Saito; Hirosuke Oba; Yuma Yoshida; Junya Terasawa; Yosuke Umehara; Norio Suganuma; Masayoshi Kawaguchi; Ryo Ohtomo; Isolation and Phenotypic Characterization of Lotus japonicus Mutants Specifically Defective in Arbuscular Mycorrhizal Formation. *Plant And Cell Physiology* **2014**, *55*, 928-941, 10.1093/pcp/pcu024.

34. John Ward; Anke Reinders; Bravo A; Brands M; Wewer V; Dörmann P; Harrison Mj; Faculty Opinions recommendation of Arbuscular mycorrhiza-specific enzymes FatM and RAM2 fine-tune lipid biosynthesis to promote development of arbuscular mycorrhiza.. *Faculty Opinions – Post-Publication Peer Review of the Biomedical Literature* **2020**, *214*, , 10.3410/f.727479982.793569628.
35. Xinguang Zhu; Jiang Y; Wang W; Xie Q; Liu N; Liu L; Wang D; Zhang X; Yang C; Chen X; et al. Faculty Opinions recommendation of Plants transfer lipids to sustain colonization by mutualistic mycorrhizal and parasitic fungi.. *Faculty Opinions – Post-Publication Peer Review of the Biomedical Literature* **2017**, *356*, , 10.3410/f.727697785.793533611.
36. John Ward; Anke Reinders; Keymer A; Pimprikar P; Wewer V; Huber C; Brands M; Bucerius Sl; Delaux Pm; Klingl V; et al. Faculty Opinions recommendation of Lipid transfer from plants to arbuscular mycorrhiza fungi.. *Faculty Opinions – Post-Publication Peer Review of the Biomedical Literature* **2020**, *6*, , 10.3410/f.727822214.793569629.
37. Ivo Feussner; Till Ischebeck; Luginbuehl Lh; Menard Gn; Kurup S; Van Erp H; Radhakrishnan Gv; Breakspear A; Oldroyd Ged; Eastmond Pj; et al. Faculty Opinions recommendation of Fatty acids in arbuscular mycorrhizal fungi are synthesized by the host plant.. *Faculty Opinions – Post-Publication Peer Review of the Biomedical Literature* **2018**, *356*, , 10.3410/f.727697782.793545176.
38. Vera Wewer; Mathias Brands; Peter Dörmann; Fatty acid synthesis and lipid metabolism in the obligate biotrophic fungus Rhizophagus irregularis during mycorrhization of Lotus japonicus. *The Plant Journal* **2014**, *79*, 398-412, 10.1111/tpj.12566.
39. Yuuki Kobayashi; Taro Maeda; Katsushi Yamaguchi; Hiromu Kameoka; Sachiko Tanaka; Tatsuhiro Ezawa; Shuji Shigenobu; Masayoshi Kawaguchi; The genome of Rhizophagus clarus HR1 reveals a common genetic basis for auxotrophy among arbuscular mycorrhizal fungi. *BMC Genomics* **2018**, *19*, 465, 10.1186/s12864-018-4853-0.
40. Quan Zhang; Laura A. Blaylock; Maria J. Harrison; Two Medicago truncatula Half-ABC Transporters Are Essential for Arbuscule Development in Arbuscular Mycorrhizal Symbiosis[W]. *The Plant Cell* **2010**, *22*, 1483-1497, 10.1105/tpc.110.074955.
41. Caroline Gutjahr; Dragica Radovanovic; Jessika Geoffroy; Quan Zhang; Heike Siegler; Marco Chiapello; Leonardo Casieri; Kyungsook An; Gynheung An; Emmanuel Guiderdoni; et al. The half-size ABC transporters STR1 and STR2 are indispensable for mycorrhizal arbuscule formation in rice. *The Plant Journal* **2011**, *69*, 906-920, 10.1111/j.1365-313x.2011.04842.x.