Biodiversity and Distribution of Arbuscular Mycorrhizal Fungi in Korea

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ABSTRACT: In this study, we summarized previous studies on diversity and distribution of arbuscular mycorrhizal fungi (AMF) for last 30 years in Korea. According to a review of the literature concerning AMF in Korea, 14 genera and 89 species have been recorded. Host plants for AMF are very diverse and include crop species and woody plants in natural forests. Based on the achievements of the last 30 years of study on AMF, we anticipate that relatively more intensive studies of the functional and genetic diversity of AMF will be conducted.

KEYWORDS: Arbuscular mycorrhiza, Distribution, Diversity, Glomeromycota, Korea

Introduction

Arbuscular mycorrhizal fungi (AMF), which maintain symbiotic relationships with most terrestrial plants, appeared on land more than 460 million years ago, and they helped plants adapt to the terrestrial environment [1]. AMF evolved specialized organs such as arbuscules, vesicles, etc., to interact with roots of plants and they provide resistance to environmental stresses (e.g., draught and salinity), help defend against disease, and absorb minerals, all of which benefit the host plants. The number of species of vascular plants worldwide is estimated at approximately 270,000 [2], while that of AMF is around 240 [3]; this asymmetric symbiotic relationship has generated tremendous academic interest. It is generally accepted that AMF exhibit relatively high genetic and functional diversity to overcome their limited species diversity [4].

In Korea, the history of AMF-related study is relatively short (ca. 30 years). Vascular plants distributed in the Korean peninsula have been reported to contain 3,000 to 5,000 taxa [5,6]; however, precise estimates of AMF species in Korea are currently lacking. Here, we review the state of AMF research in Korea in an attempt to determine the diversity of AMF species and their host plants in order to provide a basis for future AMF studies. Published papers were examined to ascertain the results of AMF-related research carried out in Korea, and a taxonomical treatment was conducted according to Schüßler and Walker [3].

AMF species diversity

A total of 89 species of AMF have been reported in Korea; however, new species have not been discovered (Table 1). Among them, species in the genera *Acaulospora* and *Glomus* have the most abundant (19 species), followed by *Scutellospora* (15 species), *Pascipora* and *Paraglomus* (two species each), and *Diversispora* and *Redeckera* (one species each). *Gigaspora margarita* was the most frequently appeared species in the literatures. Also, *Acaulospora scrobiculata*, *Funneliformis mosseae* and *Sclerocystis rubiformis* were also frequently appeared in the literatures.

In most of studies, AMF were identified using morphological characteristics of spores extracted from field-collected soils. Of the 89 AMF species, approximately 25% was identified by using both morphological and molecular data, but the remainder by using only morphological characteristics (Table 1). AMF, compared with
Table 1. List of Glomeromycota studied on different sites in Korea

| Species names                  | Study type | Reference |
|--------------------------------|------------|-----------|
| *Acaulospora bireticulata*    | Mor        | [7-12]    |
| *(A. colombiana)*              | Mor        | [12]      |
| *(A. denticulata)*             | Mor        | [10, 13, 14] |
| *(A. dilatata)*                | Mor        | [15]      |
| *(A. elegans)*                 | Mor        | [10, 12, 16] |
| *(A. foveata)*                 | Mor        | [10, 17]  |
| *(A. kentensis)*               | Mor        | [12]      |
| *(A. laevis)*                  | Mor        | [12, 16-20] |
| *(A. lacunosa)*                | Mor        | [12]      |
| *(A. longula)*                 | Mor, DNA   | [12, 19-22] |
| *(A. mellea)*                  | Mor, DNA   | [12, 22]  |
| *(A. morrowiae)*               | Mor        | [12, 14, 19] |
| *(A. myriocarpa)*              | Mor        | [23]      |
| *(A. rehmmii)*                 | Mor        | [10, 12, 24] |
| *(A. rugosa)*                  | Mor        | [12, 19]  |
| *(A. scrobiculata)*            | Mor, DNA   | [8, 12-14, 16-20, 25-28] |
| *(A. spinosa)*                 | Mor, DNA   | [9, 12, 16, 21, 23, 29] |
| *(A. sporocarpia)*             | Mor        | [12]      |
| *(A. undulata)*                | Mor        | [16, 20]  |
| *(Ambispora appendicula)*      | Mor        | [10, 12, 24] |
| *(A. fecundispora)*            | Mor        | [14, 19]  |
| *(A. leptoticha)*              | Mor, DNA   | [22, 30]  |
| *(Claroideoglomus claroideum)* | Mor, DNA   | [24, 30]  |
| *(C. lamellosum)*              | Mor, DNA   | [30]      |
| *(C. etunicatum)*              | Mor, DNA   | [14, 21, 23, 30] |
| *(Diversispora spurca)*        | Mor, DNA   | [12, 31]  |
| *(Funneliformis vesiculifrum)* | Mor        | [11, 28]  |
| *(F. mosseae)*                 | Mor, DNA   | [12, 14, 15, 17, 20, 21, 24, 25, 30, 32] |
| *(F. calchedonium)*            | Mor, DNA   | [10, 16, 18, 23, 24, 32] |
| *(F. constrictum)*             | Mor        | [12, 13, 17, 18, 24] |
| *(F. geosporum)*               | Mor        | [11, 12, 14, 25, 28] |
| *(Gigaspora albida)*           | Mor        | [33]      |
| *(G. decipiens)*               | Mor        | [8-10, 12, 17, 23, 24] |
| *(G. gigantea)*                | Mor, DNA   | [8, 10, 12, 17, 30] |
| *(G. margarita)*               | Mor, DNA   | [8, 12-14, 16, 17, 19-22, 25, 27-29, 34, 35] |
| *(G. rosea)*                   | Mor        | [35]      |
| *(Glomus aggregatum)*          | Mor        | [14, 20, 25, 28] |
| *(G. albidum)*                 | Mor        | [8, 12, 16, 18-20] |
| *(G. ambisporum)*              | Mor        | [10, 25]  |
| *(G. australis)*               | Mor        | [13]      |
| *(G. boreale)*                 | Mor        | [12]      |
| *(G. cerebriforme)*            | Mor        | [12]      |
| *(G. convolutum)*              | Mor        | [13, 28]  |
### Table 1. List of Glomeromyctes studied on different sites in Korea (continued)

| Species names                        | Study type | Reference                              |
|--------------------------------------|------------|----------------------------------------|
| *G. deserticola* Trappe, Bloss & Menge | Mor        | [9, 11, 19]                            |
| *G. dimorphicum* Boyetchko & Tewari  | Mor        | [19, 36]                               |
| *G. flavisporum* (Lange & Lund) Trappe & Gerd. | Mor   | [13, 28]                               |
| *G. glomerulatum* Sieverd.           | Mor        | [13, 16, 23]                           |
| *G. heterosporum* Sm. & Schenck      | Mor        | [17, 20]                               |
| *G. hoi* Berch & Trappe              | Mor        | [10]                                   |
| *G. invernaium* Hall                 | Mor        | [20, 24]                               |
| *G. macrocarpum* Tul. & Tul.         | Mor        | [15, 16, 20]                           |
| *G. microcarpum* Tul. & Tul.         | Mor        | [20, 23]                               |
| *G. monosporum* Gerd. & Trappe       | Mor        | [15, 24]                               |
| *G. reticulatum* Bhattacharjee & Mukerji | Mor    | [15]                                   |
| *G. tortuosum* Schenck & Sm          | Mor        | [13, 16, 23, 28]                      |
| *Pacispora chimonobambusae* (Wu & Liu) Sieverd. & Oehl | Mor   | [24]                                   |
| *P. scintillans* (Rose & Trappe) Sieverd. & Oehl | Mor   | [16, 19]                               |
| *Paraglomus brasilianus* (Spain & Miranda) Morton | DNA  | [31]                                   |
| *P. occultum* (Walker) Morton & Redecker | Mor, DNA  | [7, 12, 19, 21, 22, 30, 37]             |
| *Racocetra castanea* (Walker) Oehl, Souza & Sieverd. | Mor, DNA | [30]                                   |
| *R. coralloidea* (Trappe, Gerd. & Ho) Oehl, Souza & Sieverd | Mor                     | [10, 20, 25, 27]                      |
| *R. fulgida* (Koske & Walker) Oehl   | Mor        | [12]                                   |
| *R. gregaria* (Schenck & Nicolson) Oehl | Mor       | [8, 12, 14, 24, 28]                   |
| *R. minuta* (Ferrer & R.A. Herrera) Oehl | Mor    | [12]                                   |
| *R. persica* (Koske & C. Walker) Oehl | Mor        | [9, 12, 28]                           |
| *R. verrucosa* (Koske & Walker) Oehl, Souza & Sieverd | Mor        | [16, 36]                               |
| *R. wereusiae* (Koske & Walker) Oehl, Souza & Sieverd | Mor, DNA | [30]                                   |
| *Rebeciera pulvinatum* (Henn.) Walker & Schüssler | Mor | [8, 16, 18]                           |
| *Rhizophagus clarus* (Nicolson & Gerd.) Walker & Schüßler | Mor, DNA | [7, 17, 19, 21, 30, 35]               |
| *R. diaphanous* (Cano & Dalpé) Walker & Schüßler | Mor | [13, 28]                               |
| *R. fasciculatus* (Thaxt.) Walker & Schüßler | Mor, DNA | [12, 14, 15, 32]                     |
| *R. intraradices* (N.C. Schenck & Sm.) Walker & Schüßler | Mor, DNA | [7, 14, 35]                           |
| *R. manihotis* (Howeler, Sieverd. & Schenck) Walker & Schüßler | Mor | [8, 13]                               |
| *R. proliferus* (Blaszk., Kôvács & Balázs) Walker & Schüßler | Mor, DNA | [32, 38]                             |
| *Sclerocystis clavispora* Trappe      | Mor        | [17, 39, 40]                           |
| *S. liquidambarisp* Wu & Chen         | Mor        | [39, 40]                               |
| *S. sinuosa* Ger. & Bakshi           | Mor, DNA   | [12, 15, 17, 37-40]                   |
| *S. microcarpus* S.H. Iqbal & Perveen | Mor    | [13]                                   |
| *S. rubiformis* Gerd. & Trappe        | Mor        | [10-12, 14-17, 19, 28, 39, 40]         |
| *S. taiwanensis* Wu & Chen            | Mor        | [17, 39, 40]                           |
| *Scutellospora arenicola* Koske & Halvorson | Mor   | [24]                                   |
| *S. aurigloba* (Hall) Walker & Sanders | Mor, DNA | [7, 10, 12, 20, 30]                   |
| *S. calospora* (Nicolson & Gerd.) Walker & Sanders | Mor | [10, 12, 16, 17, 23, 40]               |
| *S. cerradensis* Spain & Miranda     | DNA        | [30]                                   |
| *S. dipapillosa* (Walker & Koske) Walker & Sanders | Mor | [12]                                   |
| *S. erythops* (Koske & Walker) Walker & Sanders | Mor, DNA | [8, 12, 14, 17]                     |
vascular plants and animals, have few key morphological characteristics and the morphology of spores extracted from field soil has been affected by various environmental factors, leading to misidentification; thus, sound molecular data are needed for accurate AMF identification.

**Host plant diversity**

Host plants for AMF are divided into three categories, herbaceous, woody, and crop species, and, in total, AMF were found from about 100 host plants (Table 2). Among them, about 25% are crop species, 24% woody plants, and 51% herbaceous plants. Most crop species are also herbaceous plants; thus, it would be reasonable to focus on woody plants for investigating AMF biodiversity. The literature shows that most host plants are common species; thus, rare species such as alpine or endangered species that are sensitive to climatic change or human development also need to be investigated.

**Regional diversity**

The distribution of sampling sites for AMF in Korea to date is illustrated in Fig. 1. The region of greatest focus

| Species names Study type | Reference |
|-------------------------|-----------|
| S. gilmorei (Trappe & Gerd.) Walker & Sanders | Mor | [7, 12, 17, 20] |
| S. heterogama (Nicolson & Gerd.) Walker & Sanders | Mor | [16, 25, 27, 34] |
| S. nigra (Redhead) Walker & Sanders | Mor | [12] |
| S. pellucida (Nicolson & Schenck) Walker & Sanders | Mor | [17, 19, 24, 36] |
| S. savannicola (Herrera & Ferrer) Walker & Sanders | Mor | [17] |

| Herbaceous plants | Agropyron yesoense | Lepedeza cuneata |
|------------------|-------------------|-----------------|
| Amphicarpaea edgeworthii | Lotus corniculatus var. japonicus |
| Artemisia annua | Miscanthus sinensis |
| Artemisia iwayomogi | Orostachys japonica |
| Artemisia princeps var. orientalis | Persicaria blumei |
| Artemisia scoparia | Persicaria thunbergii |
| Aster tripolium | Phragmites communis |
| Botrychium ternatum | Polygonatum odoratum var. pluriflorum |
| Calamagrostis epigeios | Sedum ozygfolium |
| Cassia mimosoidea var. nomame | Setaria viridis |
| Chenopodium ficifolium | Sedum sarmentosum |
| Commelina communis | Sonchus brachyotus |
| Chrysanthemum morifolium | Sonchus oleraceus |
| Desmodium oxyphylum | Sophora flavescens |
| Digitaria sanguinalis | Stellaria aquatic |
| Disporium smilacinum | Tephrosia kirilowii |
| Erigeron bonariensis | Theneda triandra var. japonica |
| Glycine soja | Trifolium resens |
| Impatiens balsamina | Veronica undulate |
| Imperata cylindrica | Vicia amoenae |
| Isachne globosa | Vicia unijuga |
| Ixeris dentata | Viola mandshurica |
| Kummerowia striata | Zoysia japonica |
### Table 2. Host plant species reported to be studied AMF in Korea (continued)

| Crop & Vegetables                  | Lycopersicon esculentum | Panax ginseng |
|------------------------------------|--------------------------|---------------|
| Allium cepa                        |                          |               |
| Allium fistulosum                  |                          |               |
| Allium scorodorum var. viviparum   |                          |               |
| Arachis hypogaea                   |                          |               |
| Brassica napus                     |                          |               |
| Capsicum annuum                    |                          |               |
| Cucumis meto var. makuwa          |                          |               |
| Cucumis sativus                    |                          |               |
| Eucalyptus esculentum              |                          |               |
| Glycine max                        |                          |               |
| Ipomoea batatas                    |                          |               |
| Lactuca sativa                     |                          |               |
| Woody plants                       |                          |               |
| Albizia julibrissin                |                          |               |
| Amorpha fruticosa                  |                          |               |
| Citrus unshiu                      |                          |               |
| Chamaecyparis obtusa               |                          |               |
| Chamaecyparis pisifera             |                          |               |
| Cryptomeria japonensis             |                          |               |
| Dendropanax morifera               |                          |               |
| Indigofera kirilowii               |                          |               |
| Lespedeza bicolor                  |                          |               |
| Lespedeza chisianensis             |                          |               |
| Lindera obtusiloba                 |                          |               |

Fig. 1. AMF sampling sites in Korea.
is the center of South Korea (e.g., Chungbuk province and the regions in its vicinity). Therefore, these would be appropriate reference sites for selecting new sampling sites for future studies of AMF. The northern and the southern part of South Korea have not been evaluated extensively in AMF studies. The vegetation in the southern Korea is different from that in the rest of Korea, and similar to that in other countries such as southern China and Kyushu in Japan. Moreover, these countries share some plant species; thus, comparative analysis of AMF between plants or between regions of these countries would be possible. In the case of the north western Korea, there are many alpine regions; hence, its diversity with respect to alpine plants and geological features would likely affect AMF species diversity and distribution.

**Conclusion**

From the perspective of this review, AMF-related research in Korea is relatively narrow in scope compared with that in other countries with respect to AMF diversity. In particular, the number of investigated host plants is merely 1/300 to 1/500 of the entire Korean plant taxa, and regionally and geologically, only Chungbuk province has been investigated relatively intensively. Thus, investigations that are more comprehensive are needed to establish a more complete understanding of AMF diversity in Korea. With respect to biodiversity, basing future AMF study of undiscovered areas and host plants on the results of this review will be a good strategy for improving Korean biodiversity, including that of AMF.

**REFERENCES**

1. Redecker D, Kodner R, Graham LE. Glomalean fungi from the Ordovician. Science 2000;289:1920.
2. Guerrant EO, Havens K, Maunder M. Ex situ plant conservation: Supporting species survival in the wild: Island Press; 2004.
3. Schüßler A, Walker C. The Glomeromycota. A species list with new families and new genera. CreateSpace Independent Publishing Platform; 2010.
4. Kuhn G, Hijri M, Sanders IR. Evidence for the evolution of multiple genomes in arbuscular mycorrhizal fungi. Nature 2001;414:745-8.
5. Lee TR. Illustrated Flora of Korea. Seoul: Hyangmunsa; 1985.
6. Lee YN. Flora of Korea. Seoul: Kyo-Hak Publishing Company; 2004.
7. Eom AH, Lee SS. Endomycorrhizal fungi identified on the soils in forest and coast areas. Kor J Mycol 1989;17:14-20.
8. Eom AH, Lee SS. Endomycorrhizal fungi found from the soils of the communities of Persicaria thunbergii H. Gross. Kor J Mycol 1990;18:26-41.
9. Mun HT, Kim CK, Choe DM. Effect of Vesicular - arbuscular mycorrhiza on the growth of bell pepper and corn seedlings. Kor J Mycol 1990;13:1-8.
10. Sohn BK, Kim KS. Studies on the indigenous vesicular-arbuscular mycorrhizal fungi (VAMF) in horticultural crops grown under greenhouse: 2. Identification of the indigenous VAMF distributed in greenhouse soil. Kor J Soil Sci Fertil 1991;24:293-301.
11. Lee YS, Chung JB, Moon DK. Identification of mycorrhizal fungi identified on Citrus orchard soils in the island of Cheju. Kor J Mycol 1998;26:97-102.
12. Lee KJ, Lee KH, Castillo ET, Budi SW. Biodiversity, spore density and root colonization of arbuscular mycorrhizal fungi at expressway cut-slopes in Korea. J Kor For Soc 2009;98:539-47.
13. Kim JT, Kim CK. Vesicular - arbuscular mycorrhizal fungi found in the soils around the roots of the leguminous plants. Kor J Mycol 1992;20:171-82.
14. Eom AH, Tae MS, Lee JK. Diversity of arbuscular mycorrhizal fungi in arable and natural soils in Korea. J Ecol Environ 2004;27:179-84.
15. Koh SD, Kim DJ, Ji SH. Morphological studies on arbuscular mycorrhizal spores in relation to coal - waste vegetations. Bull Sci Educ 2000;16:57-64.
16. Ahn TK, Lee MW, Lee SS. Ecological study on arbuscular mycorrhizal fungi in the soils around leguminous plant in Korea. Kor J Mycol 1992;20:204-15.
17. Gu CD. Species diversity of arbuscular mycorrhizal fungi community depending on environmental conditions of forest soils. J Kor Soc Environ Restor Technol 2000;3:70-9.
18. Koh SD, Lee HH. Studies of species and distribution of vesicular - arbuscular mycorrhizal fungi in relation to salt - marsh plants. Kor J Mycol 1984;12:175-82.
19. Lee SS, Eom AH, Lee OH, Kim MK, Kim SI. Descriptions of some arbuscular mycorrhizal fungi produced under artificial conditions and collected in Korea. Kor J Mycol 1993;21:85-92.
20. Choi KD, Ka KH, Lee YS, Shim JO, Lee SS. Diversity of arbuscular mycorrhizal fungi in Paekryung and Daecheong Islands. Microbiology 2000;28:133-41.
21. Lee JE, Eom AH. Effect of organic farming on spore diversity of arbuscular mycorrhizal fungi and glomalin in soil. Mycobiology 2009;37:272-6.
22. Park SH, Eo JK, Ka KH, Eom AH. Diversity of arbuscular mycorrhizal fungi of woody plants in Mt. Munan. Kor J Mycol 2011;39:1-6.
23. Lee SS, Ka KH, Lee SK, Peak KY. Vesicular - arbuscular mycorrhizal fungi found at the horticultural and cultivated plants. Kor J Mycol 1991;19:186-202.
24. Koh SD, Park JY. Study to Species composition and distribution of arbuscular mycorrhizal fungi(AMF) at Shinduri sandy dune in Boryung district, Chungnam province. Bull Sci Educ 2003;19:189-203.
25. Ka KH, Lee SS, Lee MW. Vesicular-arbuscular mycorrhizal fungi found from the soils of plant communities. Kor J Mycol 1990;18:191-7.
26. Ka KH, Lee SS, Lee MW. New description of Acaulospora
*scrobiculata* collected in Korea. Kor J Mycol 1990;18:178-80.

27. Lee SS, Ryu CN. Symbiosis of arbuscular mycorrhizae on the plant roots. Kor J Mycol 1992;20:126-33.

28. Kim JT, Lee KH, Jung BC, Kim CK. Symbiotic properties of arbuscular mycorrhizal fungi and sand dune plants. Kor J Mycol 1993;21:235-45.

29. Park HM, Nam MH, Kang HW, Lee JS, Ko JY, Kang UG, Park KB. Density of arbuscular mycorrhizal spore of plastic film house soil in Yeongnam area and characteristics of AMF in vitro. Kor J Mycol 1999;32:203-9.

30. Lee JK, Park SH, Eom AH. Molecular identification of arbuscular mycorrhizal fungal spores collected in Korea. Mycobiology 2006;34:7-13.

31. Eom AH, Eo JK, Kim DH, Jeong HS. Identification of arbuscular mycorrhizal fungi colonizing *Panax ginseng* Using 18S rDNA sequence. J Kor Sci Appl Biol Chem 2004;47:182-6.

32. Lee SW, Lee EH, Eom AH. Effects of organic farming on communities of arbuscular mycorrhizal fungi. Mycobiology 2008;36:19-23.

33. An TJ, Shin YS, Lee SE, Ahn YS, Kim YG, Park CB, Yu SH. Antifungal activity of *Impatiens balsamina* against ginseng pathogen *Alternaria panax*. Kor J Med Crop Sci 2009;17:464-9.

34. Koo CD. Arbuscular mycorrhizal fungus inoculation effect on Korean ash tree seedlings differs depending upon fungal species and soil conditions. J Kor For Soc 1997;86:466-75.

35. Sohn BK, Kim HL, Kim YJ. Density of arbuscular mycorrhizal fungi and chemical properties of soils in seasoning crop cultivation. Kor J Soil Sci Fertil 2003;36:145-53.

36. Ka KH, Ryu CN, Lee SS. Identification of Several Endomycorrhizal Fungi from the Communities of *Cassia mimosoides* var. *nomame* Makino. Plant Pathol J 1990;6:1-7.

37. Eo JK, Eom AH. The Effect of benomyl treatments on ginsenosides and arbuscular mycorrhizal symbiosis in roots of *Panax ginseng*. J Ginseng Res 2009;33:256-9.

38. Lee JK, Eom AH, Lee SS. Identification of arbuscular mycorrhizal fungi from *Botrychium ternatum* native in Korea. Mycobiology 2004;32:179-85.

39. Koo CD, Kim TH, Yi CK, Lee WK, Kang CH, Lee BC, Lee SK. Sporocarp - forming, arbuscular mycorrhizal fungi, *Glo- mus* spp. in forest soils of Korea. Kor J Mycol 1992;20:29-36.

40. Lee SK, Eom AH, Lee SS. Population changes of arbuscular mycorrhizalspores in the different soil environments. Kor J Mycol 1992;20:134-43.