Arbuscular Mycorrhizae : From Biodiversity to Application

Written by Fayuan Wang and Zhaoyong Shi

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Preface

In the symbiotic associations of plant and fungi, arbuscular mycorrhiza, which is formed between plants and Glomeromycota fungi, has the widest distribution in the nature. Arbuscular mycorrhizal (AM) fungi inhabit a variety of ecosystems including agricultural lands, forests, grasslands and various stressful environments, and colonize the roots of most plants, including bryophyte, pteridophyte, gymnosperm and angiosperm, etc.. They are recognized as an important, widespread component of most terrestrial ecosystems, benefiting plant establishment by enhancing plant nutrient acquisition, improving soil quality, and increasing resistance to environmental stresses, and also playing significant roles in maintaining plant biodiversity, ecosystem variability and productivity, and in remediating environmental problems.

According to the latest taxonomy, AM fungi belong to the Glomeromycota phylum, including 14 families and 26 genera. To date, although only fewer than 200 species of AM fungi have been described, numerous studies on AM fungal diversity in different ecosystems worldwide have shown that AM fungi distribute globally. A total of 134 AM fungi species within 13 genera, including 12 new species, have been reported in various environments in China since the earliest studies in 1980's. Although considerable research efforts have been carried out on AM fungal biodiversity, these studies are unsystematic and not enough. China has a large area of land and diverse ecosystems with various environmental factors, thus AM fungal resources and diversity may be abundant and need study systematically.

The book provided the authors' latest research results. The first four chapters summarily reviewed AM fungal biodiversity in China, and then typically studied AM fungal biodiversity in forest ecosystems, desert ecosystems, and the saline-alkali soil. The latter six chapters focused on the application of AM fungi in improving plant nutrition, accelerating the environmental remediation of polluted sites, and improving the quality and safety of agricultural products.

Dr. Fayuan Wang wrote approximately 146 000 words in Chapter 1, Chapter 4, and Chapters 6-10, and Dr. Zhaoyong Shi wrote another 140 000 words in Chapters 2-3, and Chapter 5.

We have referred much previously published papers in the whole manuscript (especially in the first Chapter). The references are provided in the final section of the book, but we wish to give special thanks to all the authors and publishers. The studies involved in this book were financed by the National Natural Science Foundation (Grant Nos. 40801120 and 40971150) and the China Postdoctoral Science Foundation. We also thank the Scholarly Monograph Publication Funds of Henan University of Science and Technology, for providing financial support towards publication of the manuscript.

Contents

Chapter 1 Biodiversity of Arbuscular Mycorrhizal Fungi in China

1.1 Introduction

Arbuscular mycorrhizal (AM) fungi are extremely common symbioses in terrestrial ecosystems, associating with about 80% of plant families worldwide. They are recognized as an important, widespread component of most terrestrial ecosystems, benefiting plant establishment by enhancing plant nutrient acquisition, improving soil quality, and increasing resistance to environmental stresses (Smith and Read, 1997), and also playing an important role in plant biodiversity, ecosystem variability and productivity. According to the latest taxonomy, AM fungi belong to the Glomeromycota phylum, including 14 families and 26 genera. To date, although only fewer than 200 species of AM fungi have been described (Redecker and Philipp, 2006), numerous studies on AM fungal diversity in different ecosystems worldwide have shown that AM fungi distribute globally (Treseder and Cross, 2006).

China is situated in the eastern part of Asia, with a coastline of 18 000 km and a total land area of 9.6 million km^2. Its territory extends over 50° of latitude from north to south, embracing the equatorial belt, the tropics, the subtropics, the moderate temperate zone, and the cold temperate zone. From east to west, China extends over 62° of longitude with land covered by forests, grasslands, deserts, plains, hills, and mountains. China has a marked continental monsoonal climate characterized by great variety. Northerly winds prevail in winter, while southerly winds reign in summer. China has 94.97 million ha of cultivated land, 400 million ha of grasslands, and 133.7 million ha of forests. The diversity of plant species in China is extraordinary, about 30 000 or one-eighth of the world total.

Studies on AM fungal biodiversity in China began in the 1980's. In 1984, Tang

and Zang reported the first new AM fungus *Glomus citricolum* (Tang and Zang, 1984). Thereafter, more and more survey work and classification of AM fungi within China were carried out. Over the past 20 years, more than 100 papers on AM fungal biodiversity have been published. This review aims to summarize the advances in AM fungal biodiversity, including species diversity, habitat diversity and host diversity within China.

1.2 Materials and Methods

The data were obtained by collecting the published reports about arbuscular mycorrhizal fungi in China.

1.3 Results

1.3.1 AM fungal species diversity

A total of 134 AM fungi species within 13 genera have been reported in the rhizosphere of different plants in various environments in China, including 12 new species (Table 1-1). The most common and widely distributed genus is *Glomus* (69 species), and then *Acaulospora* (28 species) and *Scutellospora* (17 species).

Table 1-1 AM fungi reported in China

AM fungus	References
Acaulospora bireticulata Rothwell & Trappe	Peng et al., 1990
Acaulospora capsicula Blaszk.	Cai et al., 2007
Acaulospora cavernata Blaszk.	Zhang et al., 2007
Acaulospora colossica P. A. Schultz, J. D. Bever & J. B. Morton	Cai et al., 2009
Acaulospora delicata Walker, Pfeiffer & Bloss	Zhao et al., 2006
Acaulospora denticulata Sieverding & Toro	Wu et al., 1995
Acaulospora dilatata Morton	Zhang et al., 1998
Acaulospora elegans Trappe & Gerd.	Hu, 1988
Acaulospora excavata Ingleby & Walker	Zhang et al., 2001
Acaulospora foveata Trappe & Janos	Wu and Chen, 1986
Acaulospora gedanensis Błaszk.	Gao et al., 2006

AM fungus	References
Acaulospora koskei Blaszk.	Zhang and Guo, 2005
Acaulospora lacunosa Morton	Gai and Liu, 2000
Acaulospora laevis Gerd. & Trappe	Wu and Chen, 1986
Acaulospora longula Spain & Schenck	Zhang and Wang, 1991
Acaulospora mellea Spain & Schenck	Hu, 1988
Acaulospora morrowae Spain & Schenck	Hu, 1988
Acaulospora myriocarpa Spain & Schenck	Hu, 1988
Acaulospora nicolsonii Walker, Reed & Sanders	Zhang et al., 2007
Acaulospora polonica Blaszk.	Zhang et al., 2001
Acaulospora rehmii Sieverd. & Toro	Shi et al., 2003
Acaulospora rugosa Morton	Zhang et al., 1998
Acaulospora scrobiculata Trappe	Wu and Chen, 1986
Acaulospora spinosa Walker & Trappe	Hu, 1988
Acaulospora taiwania Hu*	Hu, 1988
Acaulospora tuberculata Janos & Trappe	Zhao and Du, 1997
Acaulospora undulata Sieverd.	Zhang et al., 2001
Acaulospora paulinae J. Błaszkowski	Cai et al., 2008
Ambispora leptoticha Walker, Vestberg & Schuessler	Hu, 1988
Archaeospora trappei (Ames & Linderman) Morton & Redecker emend Spain	Wu and Chen, 1986
Diversispora spurca (Pfeiff., Walker & Bloss) Walker & Schüssler	Zhang et al., 2007
Diversispora versiforme (Karst) Berch	Zhang and Wang, 1991
Entrophospora baltica Blaszk., Madej & Tadych	Cai et al., 2007
Entrophospora infrequens (Hall) Ames & Schneid.	Wu and Chen, 1986
Funneliformis xanthium (Blaszkowski, Blanke, Renker & Buscot) C. Walker & A. Schüßler	Cai et al., 2012
Gigaspora decipiens Hall & Abbott	Liu et al., 2002
Gigaspora gigantea (Nicol. & Gerd.) Gerd. & Trappe	Wu and Chen, 1986
Gigaspora margarita Becker & Hall	Peng et al., 1990
Gigaspora ramisporophora Spain, Sieverd. & Schenck	Cai et al., 2007
Glomus aggregatum Schenck & Smith	Hu, 1988
Glomus albidum Walker & Rhodes	Wang and Hu, 1989
Glomus ambisporum Smith & Schenck	Wang and Hu, 1989
Glomus arenarium J. Blaszkowski, M. Tadych & T. Madej	Cai et al., 2012
Glomus aureum F. Oehl	Cai et al., 2008
Glomus australe (Berk.) Berch	Zhang et al., 2003

AM fungus	References
Glomus badium Oehl, Redecker & Sieverd.	Zhang et al., 2007
Glomus brohultii Herrera, Ferrer & Sieverd.	Bao et al., 2007
Glomus caledonium (Nicolson & Gerd.) Trappe & Gerd.	Wu and Chen, 1986
Glomus canadense (Thaxter) Trappe & Gerd.	Shi et al., 2004
Glomus citricolum Tang & Zang*	Tang and Zang, 1984
Glomus claroideum Schenck & Sm. emend Walker & Vestberg	Peng et al., 1990
Glomus clarum Nicolson & Schenck	Hu, 1988
Glomus clavisporum (Trappe) Almeida & Schenck	Wu and Chen, 1986
Glomus constrictum Trappe	Fang et al., 1986
Glomus convolutum Gerd. & Trappe	Zhang et al., 2003
Glomus coremioides (Berk. & Broome) Redecker & Morton	Wu and Chen, 1986
Glomus coronatum Giovann.	Zhang et al., 2007
Glomus cunnighamia Hu*	Hu, 1988
Glomus delhiense Mukerji, Blattacharjee & Tewari	Liu et al., 2001
Glomus diaphanum Morton & Walker	Peng et al., 1990
Glomus dimorphicum Boyetchko & Tewari	Wang et al., 1998
Glomus dolichosporum Zhang & Wang*	Zhang et al., 1997
Glomus eburneum Kenn., Stutz & Morton	Wang et al., 2006
Glomus etunicatum Becker & Gerd.	Wu and Chen, 1986
Glomus fasciculatum (Thaxter) Gerdemann & Trappe emend. Walker & Koske	Wu and Chen, 1986
Glomus flavisporum (Lange & Lund) Trappe & Gerd.	Gao et al., 2006
Glomus formosanum Wu & Chen*	Wu and Chen, 1986
Glomus fulvum (Berk. & Broome) Trappe & Gerd.	Wu et al., 2001
Glomus geosporum (Nicol. & Gerd.) Walker	Wang and Hu, 1989
Glomus gibbosum Blaszk.	Zhang et al., 2003
Glomus globiferum Koske & Walker	Zhang et al., 2003
Glomus glomerulatum Sieverd.	Liu et al., 2001
Glomus halonatum Rose & Trappe	Ren et al., 2005
Glomus heterosprum Smith & Schenck	Zhang et al., 2003
Glomus hoi Berch & Trappe	Wang and Hu, 1989
Glomus hyderabadensis Swarapu, Kunwar, Prasad & Manohar	Wang et al., 2006
Glomus intraradices Schenck & Smith	Fang et al., 1986
Glomus invermaium Hall	Gao et al., 2006
Glomus lamellosum Dalpe, Koske & Tews	Zhang et al., 2007
Glomus liquidambaris (Wu & Chen) Almeida & Schenck*	Wu and Chen, 1987

AM fungus	References
Glomus macrocarpum Tul. & Tul.	Hu, 1988
Glomus luteum Kenn., Stutz & Morton	Zhang and Guo, 2005
Glomus magnicaule Hall	Shi et al., 2003
Glomus manihotis Howeler, Sieverd. & Schenck	Wu et al., 1994
Glomus melanosporum Gerd. & Trappe	Wang and Liu, 2002
Glomus microaggregatum Koske, Gemma & Olexia	Zhang et al., 1996
Glomus microcarpum Tul. & Tul.	Hu, 1988
Glomus monosporum Gerd. & Trappe	Zhao, 1998
Glomus mortonii S.P. Bentivenga & B. A. D. Hetrick	Cai et al., 2012
Glomus mosseae (Nicol. & Gerd.) Gerd. & Trappe	Fang et al., 1986
Glomus multicaule Gerd. & Bakshi	Zhao and Du, 1997
Glomus multiforum Tadych & Blaszk.	Zhao et al., 2006
Glomus pakistanica Iqbal & Bushra	Hu, 1988
Glomus pallidum Hall	Peng et al., 1990
Glomus pansihalos Berch & Koske	Wang and Liu, 2002
Glomus pustulatum Koske, Friese, Walker & Dalpe	Wang and Liu, 2002
Glomus reticulatum Bhattacharjee & Mukerji	Gai et al., 2000a
Glomus rubiforme Gerdemann & Trappe	Wu and Chen, 1986
Glomus sinuosum Almeida & Schenck	Wang et al., 1992
Glomus spinosum Hu*	Hu, 2002
Glomus spinuliferum F. Oehl, A. Wiemken & E. Sieverding	Cai et al., 2009
Glomus taiwanense (Wu & Chen) Almeida & Schenck*.	Wu and Chen, 1987
Glomus tenebrosum (Thaxt.) Berch	Wang and Liu, 2002
Glomus tortuosum Schenck & Smith	Wu et al., 2000
Glomus trimurales R. E. Koske & W.L. Halvorson	Cai et al., 2012
Glomus verruculosum Blaszk.	Li et al., 2004
Glomus viscosum Nicolson	Li et al., 2004
Glomus zaozhuangianus Wang & Liu*	Wang and Liu, 2002
Intraspora schenckii E. Sieverding & S. Toro	Cai et al., 2009
Kuklospora colombiana Spain & Schenck	Zhang et al., 2003
Kuklospora kentinensis Wu & Liu*	Wu et al., 1995
Pacispora boliviana Oehl & Sieverd.	Gao et al., 2006
Pacispora chimonobambusae (Wu & Liu) Walker, Vestberg & Schuessler*	Wu et al., 1995
Pacispora robigina F. Oehl & E. Sieverding	Cai et al., 2008
Pacispora scintillans Walker, Vestberg & Schuessler	Hu, 1988
Paraglomus brasilianum J. B. Morton & D. Redecker	Cai et al., 2009

AM fungus	References
Paraglomus occltum (Walker) Morton & Redecker	Peng et al., 1990
Scutellospora aurigloba (Hall) Walker & Sanders	Peng et al., 1990
Scutellospora calospora (Nicolson & Gerd.) Walker & Sanders	Hu, 1988
Scutellospora cerradensis Spain & Miranda	Wang et al., 2006
Scutellospora coralloidea (Trappe, Gerd. & Ho) Walker & Sanders	Pan et al., 1997
Scutellospora dipapillosa (Walker & Koske) C. Walker & F. E. Sanders	Cai et al., 2009
Scutellospora dipurpurescens Morton & Koske	Zhao et al., 2006
Scutellospora erythropa (Koske & Walker) Walker & Sanders	Pan et al., 1997b
Scutellospora fulgida Koske & Walker	Wang et al., 1998
Scutellospora gilmorei (Trappe & Gerd.) Walker & Sanders	Hu, 1988
Scutellospora gregaria (Schenck & Nicol.) Walker & Sanders	Zhao, 1998
Scutellospora heterogama (Nicol. & Gerd.)Walker & Sanders	Wu et al., 1994
Scutellospora nigra (Redhead) Walker & Sanders	Hu, 1988
Scutellospora pellucida (Nicol. & Schenck) Walker & Sanders	Hu, 1988
Scutellospora persica (Koske & Walker) Walker & Sanders	Zhao, 1998
Scutellospora reticulata (Koske, Miller & Walker) Walker & Sanders	Wang et al., 1998
Scutellospora trirubiginopa Pan & Zhang*	Pan et al., 1997
Scutellospora verrucosa (Koske & Walker) Walker & Sanders	Yang et al., 2004

Notes: The scientific names are amended according to the internet information (http://www.lrz-muenchen.de/~schuessler/amphylo/).

* New species from China.

1.3.2 AM fungal habitat diversity

It has been shown that, besides farmlands (Gai et al., 2004; Peng et al., 1990; Zhang and Wang, 1991), fruit lands (Jiang et al., 2007; Liu et al., 1987), vegetable lands (Wang et al., 2006), forest lands (Fang et al., 2006; Hu, 1988), grasslands (Bao et al., 2007; Cai et al., 2005; Wang et al., 2003; Xue et al., 2007), AM fungi occurred widely in tropical rain forests (Shi et al., 2003; Shi et al., 2003; Zhao et al., 2001; Zhao et al., 2001), tropical virgin forests (Gong et al., 1994), tropical secondary forest (Fang et al., 2006), artificial forests (Gong et al., 1996; Yi et al., 1990), natural secondary forests (Chen and Zhuang, 1997), greenhouse vegetable land (Liu et al., 2001), natural reserves (Ren et al., 2005; Wu et al., 2000), altiplano grassland, etc. (Cai et al., 2005).

AM fungi occurred in all kinds of landforms all over the China, such as mountains (Shi et al., 2007; Zhang and Wang, 1991), plateaus (Cai et al., 2005; Pan et al., 1997;

Pan et al., 1997), hills (Gai and Liu, 2000), plains (Gai and Liu, 2000), islands (Liu et al., 2001), basin (Wang et al., 2006). However, AM fungal biodiversities differ from different soil climatic zones, varying with various environmental factors (Zhang et al., 1998; Zhang et al., 1999).

In recent years, AM fungal diversities in fragile ecosystems and polluted environments received more attraction, such as deserts (Bao et al., 2005; Ji et al., 2007; Tian et al., 2006), saline-alkaline soils (Sheng et al., 2007; Tang et al., 2007; Wang and Liu, 2002; Zhang et al., 2007), degraded grasslands (Wang et al., 2003), eroded soils (Pan et al., 1997; Pan et al., 1997), sewage irrigated soils (Geng et al., 2002), petroleum polluted soils (Huang et al., 2007), coal mine heaps (Wang et al., 2003), heavy metal polluted soils (Liang et al., 2007), mining disturbed soils (Zhang et al., 2006), mine tailings (Chen et al., 2005), abandoned mine lands (Liang et al., 2007).

1.3.3 AM fungal host diversity

AM fungi are ubiquitous in natural ecosystems, associating with about 80% of terrestrial plant species worldwide (Smith and Read, 1997). Most plant phyla, including bryophyte, pteridophyte, gymnosperm and angiosperm, are all able to form mycorrhizae with AM fungi. In China, crops, wild plants, tropical plants, alpine plants, halophytes, xerophyte, hydrophyte, geophyte, parasitic plants, are all found to be mycorrhizal. Only a few families, such as Cyperaceae, Braşsicaceae, Caryophyllaceae, Juncaceae, Chenopodiaceae and Amaranthaceae, are assumed never to form mycorrhizal associations or to do so rarely (Hirsch and Kapulnik, 1998). In recent years, mycorrhizae on plants of these families have been observed, such as Cyperaceae (Muthukumar et al., 2003), Amaranthaceae (Bao and Yan, 2004; Chen et al., 2001; Yang et al., 2002), Caryophyllaceae (Chen et al., 2001), and Chenopodiaceae (Liu et al., 2002; Wang and Liu, 2002).

China has about 30,000 plant species, accounting for about one eighth of the world total. Chinese researchers have done a considerable amount of work on the mycorrhizal status of plant species in terrestrial ecosystems and have examined a total of nearly 800 plant species belonging to 150 families. These plants include food crops, economic crops, vegetables, fruits, ornamental plants, Chinese medical plants, wild weeds, trees, etc. (Table 1-2). Interestingly, even some forest trees, such as *Eucalyptus* and Dipterocarpaceae, usually considered to be typically ectomycorrhizal, have been recently

found to have AM colonization (Gong et al., 1996; Shi et al., 2003; Shi et al., 2003).

Table 1-2 Plant species reported to be AM in China

Plants	Plant species		References
Food crops	*Arachis hypogaea* L. *Avena nuda* L. *Eriogonum fasciculatum* Benth. *Glycine max* Merrill. *Hordeum vulgare* L. *Ipomoea batatas* (L.) Lam. *Manihot esculenta* Crant. *Oryza sativa* L.	*Pisum satuvum* L. *Sesamum indicum* L. *Setaria italica* (L.) Beauv. *Sorghum vulgare* Pers. *Triticum aestivum* L. *Vigna rabiata* (Linn.)Wilczek *Vicia gemimiflora* Trautv. *Zea mays* L.	Gai et al., 2004; Niu, 1994; Peng et al., 1990; Wang et al., 2006; Zhang and Wang, 1991; Zhang and Tang, 2006; Zhang et al., 1996
Economic crops	*Agave sisalana* Perrine. *Boehmeria nivea* (L.) *Gaudich* *Camellia sinensis* (L.) O. Kuntze. *Cannabis sativa* L. *Coffea arabica* L. *Hevea brasiliensis* Müll.Arg	*Gossypium arboreum* Linn. *Helianthus annuus* L. *Morus alba* L. *Nicotiana tabacum* L. *Piper nigrum* L. *Saccharum sinense* L.	Fang et al., 1986; Niu, 1994; Peng et al., 1990; Wang and Hu, 1989; Zhang and Tang, 2006
Fruits	*Actinidia chinensis* Planch. *Ananas comosus* (L.) Merr. *Averrhoa carambola* L. *Canarium album* Raeusch *Carica papaya* L. *Carya cathayensis* Sargent. *Castanea mollissima* Blume. *Citrus aurantium* L. *Citrus grandis* Osbeck. *Citrus limon* Burmann *Citrus sinensis* Osbeck. *Citrus sunki* Hot. *Cocos nucifera* L. *Corylus heterophylla* Fisher. *Crataegus pinnatifolia* Bunge. *Dimocarpus longana* Lour. *Diospyros kaki* Lf. var. domestica Makino. *Eriobotrya japonica* Lindley. *Ficus carica* L. *Fortunella margarita* (Lour.) Swingle *Fragaria x ananassa* Duch.	*Gingko biloba* L. *Juglans regia* L. *Litchi chinensis* Sonn. *Macadamia ternifolia* F. Muell *Malus pumila* Mill. *Mangifera indica* L. *Manilkara zapota* (Linn.) Van Royen. *Morus alba* L. *Musa sapientum* L. *Myrica rubra* Sieb. et Zucc. *Pistacia vera* L. *Prunus armeniaca* L. *Prunus cerasus* L. *Prunus mume* Siebold & Zucc. *Prunus persica* L. *Prunus salicina* Lindl. *Psidium guajava* L. *Punica granatum* L. *Pyrus bretschneideri* Rehd. *Rubus occidentalis* L. *Vitis vinifera* L. *Zizyphus jujuba* Mill.	Cai et al., 2007; Liu et al., 1987; Niu, 1994; Tang and Zang, 1984; Wang et al., 2006; Wu et al., 1994; Zhang et al., 1992; Zhang et al., 1996; Zhou et al., 1992

Plants	Plant species		References
Vegetables	*Allium cepa* L. *Allium fistulosum* L. *Allium fistulosum* Linn. *Allium porrum* L. *Allium sativum* Linn. *Allium tuberosum* Rottl. *Amaranthus mangostanus* L. *Apium graveolens* L. *Asparagus officinalis* L. *Capsicum annuum* L. *Citrullus lanatus* (Thunb.) Matsum and Nakai *Cucumis sativus* L. *Daucus carota* L. *Dioscorea batatas* Decne *Ipomoea aquatica* Forsk. *Lablab purpureus* (L.) Sweet	*Lactuca sativa* L. *Lnffa cylindrica* Rome. *Lycopersicon esculentum* Mill. *Momordica charantia* L. *Phaseolus vulgaris* L. *Phaseolus vulgaris* Linn. *Pimpinella brachycarpa* Nakai. *Pisum sativum* L. *Solanum melongena* L. *Solanum tuberosum* L. *Spinacia oleracea* L. *Toona sinensis* (Juss.) Roem. *Vigna sesquipedalis* Koern *Vigna unguiculata* (L.) Walp. *Zanthoxylum schinifolium* Zucc. *Zingiber officinale* Roscoe *Zizania caduciflora* Hand.	Lin and Hao, 1989; Niu, 1994; Peng et al., 1990; Qiao, 2006; Zhang and Wang, 1991; Zhang et al., 1992; Zhang et al., 2006
Flowers	*Aloe vera* L. *Cymbidium ensifolium* Sw. *Dendranthema morifolium* Ram *Gerbera Jamesonii* Bolus *Gladiolus gandavensis* Van Houtte *Gynostemma pentaphylla* (Thunb.) Makino *Hamelia patins* *Jasminum sambac* (L.) Ait. *Leucaene leucocephala* (Lam.) de Wit.	*Lilium longiflorum* Thunb. *Lonicera japonica* Thunb. *Mimosa pudica* L. *Myosotis sylvatica* Ehrh. ex Hoffm. *Paeonia suffruticosa* Andrews. *Petunia hybrida* Vilm. *Prunus mume* Siebold & Zucc *Rosa chinenses* Jacq. *Rosa hybrida* Hort. *Saintpaulia ionantha* H. Wendl. *Prunus mume*	Cai et al., 2008, 2009, 2012; Guo et al., 2007; Lin and Hao, 1989; Li and Wang, 1999; Niu, 1994; Zhang et al., 1992; Yi et al., 1990; Cai et al., 2012
Medical plants	*Atractylodes macrocephala* Koidz. *Datura stramonium* L. *Gentiana scabra* Bge. *Lonicera japonica* Thunb. *Lycium chinensis* Mill. *Mentha haplocalyx* Briq. *Panax ginseng* CA Mey	*Panax notoginseng* (BurK1) F1H1Chen *Panax quiquefolium* L. *Phellodendren amurense* Rupr. *Platycodon grandiflorus* (Jacq.) A. DC. *Salvia miltiorrhiza* Bunge *Schizonepeta tenuifolia* Briq. *Scutellaria laterifolia* L.	Gao and He, 2007; Jie et al., 2007; Niu, 1994; Ren et al., 2007; Wang et al., 1998; Wei and Wang, 1991; Xing et al., 2000; Yang et al., 2007; Zhang et al., 1992

Plants	Plant species		References
Forage grasses	*Medicago sativa* L. *Trifolium repens* L *Trifolium pretense* L.	*Aneurolepidium chinense* (Trin) Kitag. *Festuca rubra* L. *Leymus chinensis* (Trin.) Tzvel.	Bao et al., 2007; Cai et al., 2005; Niu, 1994; Xue et al., 2007; Zhang et al., 1992
Wild weeds	*Aeluropus littoralis* var. *sinensis* Debx. *Agrostis stolonifera* L. *Alopecurus aequalis* Sobol. *Artemisia lavandulaefolia* DC. *Arthraxon hispidus* (Thunb.) Makino *Belamcanda chinensis* (L.) DC. *Bromus remotiflorus* (steud.) Ohwi *Cirsium setosum* (Willd.) MB. *Dendranthema indicum* (L.) Des Moul. *Digitaria ciliaris* (Retz.) Koel. *Digitaria sanguinalis* (L.) Scop. *Eleusine indica* (L.) Gaertn *Eragrostis pilosa* (L.) Beauv. *Erigeron acris* L.	*Eulalia specisa* (Debeaux) Kuntze *Imperata cylindrica* var. *major* (Nees) C. E. Hubb. *Kummerowia striata* (Thunb.) Schindl. *Orostachys fimbriatus* (Turcz.) Berger *Papaver nudicaule* L. *Plantago asiatica* L. *Poa pratensis* L. *Polypogon fugax* Nees ex Steud. *Puccinellia distans* (L.) Parl. *Setaria viridis* (L.) Beauv. *Vitex negundo* Linn. var. *heterophylla* (Franch)	Bao and Yan, 2004; Chen et al., 2001; Gai et al., 2000a; Gai et al., 2000b; Liu et al., 2002; Wang and Liu, 2002; Zhang et al., 1992
Forest trees	*Abies fargesii* Franch *Acacia* L. *Alnus* L. *Betula alnoides* Hamlit *Burretiodendron hsienmu* Chun et How *Cunninghamia lanceolata* (Lamb.) Hook. *Cupressus* L. Dipterocarpaceae	*Eucalyptus* L. Fagaceae *Phoebe* L. *Poplus* L. *Quercus* L. *Schima superba* Gardner & Champ. *Sophora* L. *Taiwania cryptomerioides* Hayata *Ulmus pumila* L.	Bao and Yan, 2004; Dong et al., 2006; Fang et al., 2007; Gong et al., 1994; Gong et al., 1996; Gong et al., 2000; Hu, 1988; Shi et al., 2003a; Shi et al., 2003b; Wu et al., 1986; Wu et al., 2000; Zhang et al., 1997

1.4 Conclusion

In the symbiotic associations of plant and fungi, arbuscular mycorrhiza, which is