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REVIEW PAPER

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Twenty years of research on community composition and species distribution of arbuscular mycorrhizal fungi in China: a review

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Abstract The biodiversity and distribution of arbuscular mycorrhizal fungi (AMF) in different ecosystems and plant communities in China has received increasing interest over the past decades. This has led to a steady increase in the number of scientific papers published on this topic. Studies have surveyed AMF-colonizing rhizospheres of most families of angiosperms, bryophytes, pteridophytes, and gymnosperms. China has about 30,000 plant species (one eighth of the plant species worldwide). A total of 104 AMF species within nine genera, including 12 new species, have been reported in environments such as croplands, grasslands, forests, and numerous disturbed environments. In this paper, we review data published over the past 20 years on AMF community composition and species distribution, the mycorrhizal status of plants, AMF spore communities in different habitats, and germplasm collections in China. Possible future trends in the study of the biodiversity of AMF are also briefly discussed. In particular, the aim of our review is to make some of the recent work published in the Chinese literature accessible to a wider international audience.

Keywords Arbuscular mycorrhizal fungi · Biogeography · China · Species richness · Vegetation diversity

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Introduction

Arbuscular mycorrhizal fungi (AMF) are ubiquitously associated with the large majority of plant families in different ecosystems across the world ranging from the tropics (Janos 1980; Zhao et al. 2001b) or arctic-alpine habitats (Haselwandter and Read 1980; Haselwandter 1987) to mesic (Rickerl et al. 1994; Ingham and Wilson 1999; Muthukumar and Udaiyan 2000) and arid habitats (Barrow et al. 1997; Stutz et al. 2000; O'Connor et al. 2002). China embraces a large diversity of climatic conditions and soil types, resulting in a wide range of ecosystems and vegetation structure. The examination of AMF began in China in the 1970s (Tang 1977). Early research focused entirely on the mycorrhizal status of plants, mostly on the degree of root colonization and spore counts in the field. The taxonomy of AMF was studied in the mid-1980s and several manuals for the identification of AMF were published in Chinese (Tang and Zang 1984; Zhang and Wang 1991a). This work led to an increase in the identification of AMF in surveys within China. The number of researchers investigating these fungi also increased. Over the past 10 years, studies have resulted in more than 100 papers on taxonomy and diversity, most of which were performed by observation of spores of AMF.

From north to south, the People's Republic of China covers the equatorial belt, the tropics, the subtropics, a moderate temperate zone and a cold temperate zone, and from east to west, the lands comprise forests, grasslands, deserts, plains, hills, and mountains. In terms of moisture, the country can be sectored from southeast to northwest into humid (32% of land area), semihumid (15%), semiarid (22%), and arid zones (31%). Climates are dominated by dry seasons and wet monsoons, and differ from region to region because of the country's extensive and complex topography. According to the climate and terrain, the mainland of China is traditionally divided into six geographical zones (Fig. 1). To the south of the Nanling Mountains, rains are prolific and temperatures are high all year round. The Yangtze and Huaihe river valleys in central south China have four distinctive seasons. In northeast

China, summer is short but with much sunshine, while winter is long and cold. Precipitation is limited in northwest China. In southwest China at low latitudes, the land is highly elevated and has characteristically vertical seasonal zones.

Due to the influences of hydrothermal conditions and geomorphology, Chinese soil distribution shows zonality in latitude and longitude. In east China, for instance, the soils vary between south and north from latosols through lateritic red earths, red earths, yellow-brown earths, and brown earths to dark brown earths, while from the coast to the interior (east to west), soils also show regular variation with decreasing humidity. For example, in the Temperate Zone, the soils vary from dark brown earths, black soils, chernozems, castenoziems, brown pedocals, and gray to brown desert soils. Agricultural soils are mostly concentrated on the eastern plains, the Loess Plateau, the Sichuan Basin, and large areas of the southeastern part of the country where the greatest population densities and the longest history of cultivation are.

This review aims to summarize the information that is presently available on plant mycorrhizal status, AMF species richness and germplasm collections, and AMF community diversity in different habitats and vegetation types within China.

Mycorrhizal status of plants

Trappe (1987) indicates that while arbuscular mycorrhiza (AM) have been recorded in all angiosperm orders examined, information is available for only about 3% of known plant species. About 30,000 plant species (one eighth of the world total) are present in China, which is almost twice the number found in the United States and Canada combined. This number includes about 8,000 species of medicinal and economically important plants and about 7,500 species of trees and shrubs. Chinese researchers have extensively examined the mycorrhizal status of plant species in terrestrial ecosystems, studying nearly 800 plant species belonging to 150 families.

Early work in China focused mainly on the mycorrhizal status of cultivated plants. Some 120 agricultural plant species, including grain, oil, and economic crops and horticultural and Chinese medicinal plants, have been found to form associations with AMF (Table 1). In addition, wild plants inhabiting a range of environments, such as heathland, mountain areas, grasslands, woodlands, and tropical forests, were also surveyed (Gong et al. 1997; Gai et al. 2000a; Zhao 2000; Chen et al. 2001; Zhao et al. 2001b, 2003; Wang and Liu 2002; Muthukumar et al. 2003; Bao and Yan 2004; Ding et al. 2004). Mycorrhizal incidence among wild herbaceous plants is consistently high, with over 90% of the species examined (about 300) exhibiting AMF colonization, and AM associations also occur in trees and shrubs of certain climatic zones. Gong et al. (1997) concluded that members of 48 plant families,

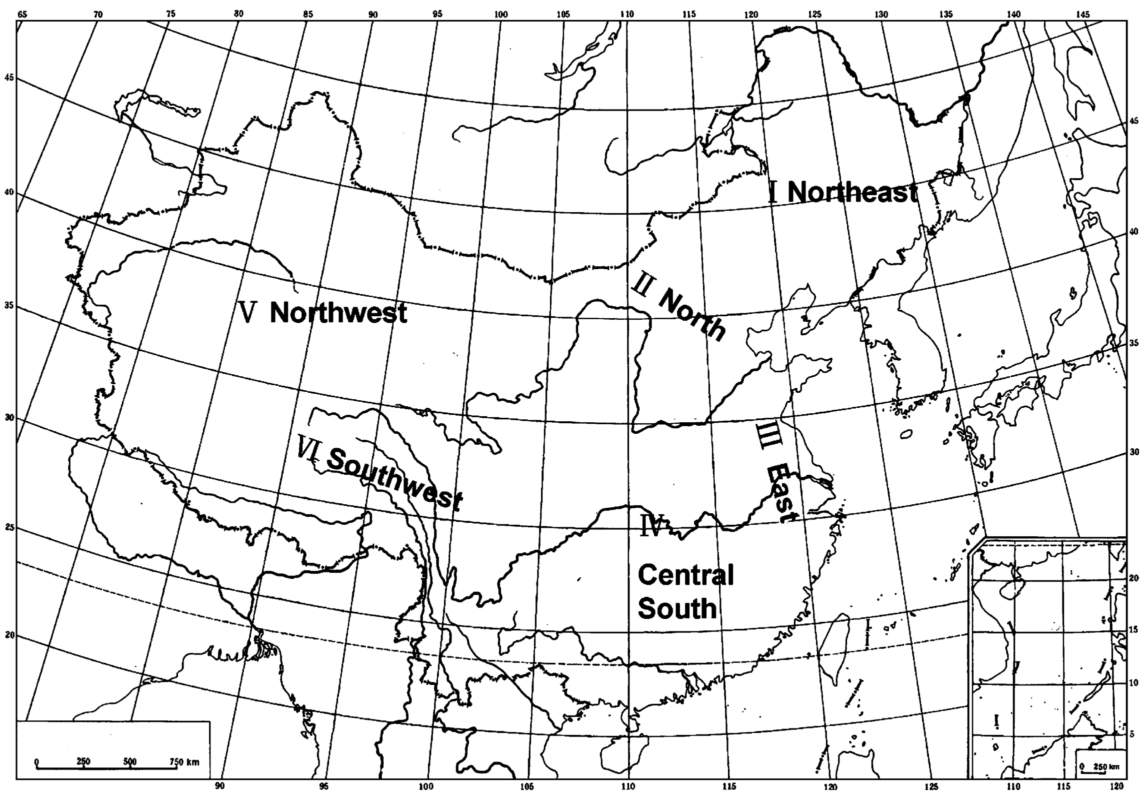

Fig. 1 Sketch map of China showing the six geographical zones

out of a total of 78, form AM associations. Other surveys have focused on subtropical and tropical vegetation (Wu et al. 2001; Zhao et al. 2001a,b; Zhang et al. 2003a). The incidence of AM tends to be higher in subtropical and tropical tree species compared with those in temperate zones. A survey in the subtropical Yunnan province showed that about 80% of tree species form AM associations (Muthukumar et al. 2003). Even the Dipterocarpaceae, typically considered to be ectomycorrhizal (Smith and Read 1997), exhibit AMF colonization in China (Shi et al. 2003a,b). Pteridophytes are of ancient origin and some members are assumed to be AM (Gemma et al. 1992). In subtropical China, AMF structures have been observed in 31 (91%) out of 34 pteridophyte species in Dujiangyan (Zhang et al. 2004a), which is very different from the results of Zhao (2000), who reported very low occurrence (17%) of AMF amongst 256 pteridophyte species in a tropical region of Yunnan, southwest China.

Some plant families are still assumed to never or rarely form mycorrhizal associations (Newman and Reddell 1987; Tester et al. 1987), such as members of the Cyperaceae, Brassicaceae, Caryophyllaceae, Juncaceae, and Amaranthaceae (Smith and Read 1997). The AM status of Cyperaceae was found to vary in different habitats of China. Muthukumar et al. (2003) found no mycorrhizal structures in three sedge species in the Yunnan province. In contrast, most of 22 ecotypes examined in nine sedge species from Tibetan grasslands were mycorrhizal (Gai et al. 2005). Muthukumar et al. (2004) reviewed current information on mycorrhizal associations in sedges, and concluded that mycorrhiza formation is greatly influenced by environmental conditions. The mycorrhizal status of some Amaranthaceae species was also studied by Chen et al. (2001) in agricultural parts of the red soil area, by Bao and Yan (2004) in the grasslands of midwestern Inner Mongolia, and by Yang et al. (2002) in the Xishuangbanna Tropical Botanical Garden in south China. Three out of eight species were found to form AM. However, all members of the Brassicaceae, Caryophyllaceae, or Juncaceae examined to date in China are nonmycorrhizal (Gai et al. 2000a; Chen et al. 2001; Bao and Yan 2004). Distinctive morphotypes of AM have also been reported in different plant species. Bao and Yan (2004) studied mycorrhiza in 125 plant species in the central and western grasslands of Inner Mongolia; out of 104 plant species investigated, 83% formed AM associations and most were of the Arum type (65%).

Spore communities in different habitats

Discrimination between AMF species and the measurement of their richness, abundance, and distribution in natural habitats is central to understanding community structure and dynamics, ecological assembly rules, and biogeographical patterns. Much of the influential work has focused on comparative geographical studies and on patterns of nonrandom (deterministic) community assem-

Table 1 Cultivated plant species reported to be arbuscular mycorrhizal in China

Grain crops[a, b, c, d, e]	
Avena nuda L.	*Oryza sativa* L.
Eriogonum fasciculatum Benth.	*Setaria italica* (L.) Beauv.
Glycine max Merrill	*Sorghum vulgare* Pers.
Hordeum vulgare L.	*Triticum aestivum* L.
Ipomoea batatas (L.) Lam.	*Vigna rabiata* (L.)Wilczek
Manihot esculenta Crant.	*Zea mays* L.
Oil crops[a, c, d, e]	
Arachis hypogaea L.	*Sesamum indicum* L.
Economic crops[b, c, f, g, h, i]	
Agave sisalana Perrine	*Helianthus annuus* L.
Boehmeria nivea (L.) Gaudich	*Hevea brasiliensis* Müll. Arg.
Camellia sinensis (L.) O. Kuntze	*Morus alba* L.
Cannabis sativa L.	*Nicotiana tabacum* L.
Coffea arabica L.	*Piper nigrum* L.
Gossypium arboreum L.	*Saccharum sinense* L.
Horticultural plants	
Fruit[b, d, e, g, i, j, k, l, m]	
Actinidia chinensis Planch.	*Fragaria × ananassa* Duch.
Ananas comosus (L.) Merr.	*Gingko biloba* L.
Averrhoa carambola L.	*Juglans regia* L.
Canarium album Raeusch	*Litchi chinensis* Sonn.
Carica papaya L.	*Malus pumila* Mill.
Carya cathayensis Sargent	*Mangifera indica* L.
Castanea mollissima Blume	*Manilkara zapota* (L.) Van Royen
Citrus aurantium L.	*Morus alba* L.
Citrus grandis Osbeck.	*Musa sapientum* L.
Citrus limon Burmann	*Myrica rubra* Sieb. et Zucc.
Citrus sinensis Osbeck	*Pistacia vera* L.
Citrus sunki Hot.	*Prunus armeniaca* L.
Cocos nucifera L.	*Prunus cerasus* L.
Corylus heterophylla Fisher	*Prunus persica* L.
Crataegus pinnatifolia Bunge	*Prunus salicina* Lindl.
Dimocarpus longana Lour.	*Psidium guajava* L.
Diospyros kaki Lf. var. *domestica* Makino	*Punica granatum* L.
Eriobotrya japonica Lindley	*Pyrus bretschneideri* Rehd.
Ficus carica L.	*Vitis vinifera* L.
Fortunella margarita (Lour.) Swingle	*Zizyphus jujuba* Mill.
Vegetables[b, c, d, e, n]	
Allium cepa L.	*Lactuca sativa* L.
Allium fistulosum L.	*Luffa cylindrica* (L.) Roem.
Allium porrum L.	*Lycopersicon esculentum* Mill.
Allium sativum L.	*Momordica charantia* L.
Allium tuberosum Rottl.	*Phaseolus vulgaris* L.
Amaranthus mangostanus L.	*Pisum sativum* L.
Apium graveolens L.	*Solanum melongena* L.
Asparagus officinalis L.	*Solanum tuberosum* L.
Capsicum annuum L.	*Spinacia oleracea* L.
Citrullus lanatus (Thunb.) Matsum & Nakai	*Toona sinensis* (Juss.) Roem.
Cucumis sativus L.	*Vigna sesquipedalis* Koern
Daucus carota L.	*Vigna unguiculata* (L.) Walp.

Table 1 (continued)

Dioscorea batatas Decne.	*Zanthoxylum schinifolium* Zucc.
Ipomoea aquatica Forsk.	*Zingiber officinale* Roscoe
Lablab purpureus (L.) Sweet	*Zizania caduciflora* Hand.
Flowers[b, e, n, o, p]	
Aloe vera L.	*Rosa chinensis* Jacq.
Leucaena leucocephala (Lam.) de Wit	*Rosa x hybrida* Hort.
Gynostemma pentaphylla (Thunb.) Makino	*Mimosa pudica* L.
Jasminum sambac (L.) Ait.	*Petunia hybrida* Vilm.
Gladiolus gandavensis Van Houtte	*Saintpaulia ionantha* H. Wendl.
Lonicera japonica Thunb.	*Lilium longiflorum* Thumb.
Paeonia suffruticosa Andrews	*Myosotis sylvatica* Ehrh. ex Hoffm.
Medicinal plants[b, e, q, r, s, t]	
Datura stramonium L	*Panax quiquefolium* L.
Lycium chinensis Mill.	*Gentiana scabra* Bge.
Mentha haplocalyx Briq.	*Schizonepeta tenuifolia* Briq.
Panax ginseng CA Mey.	

[a]Gai et al. (2004)
[b]Niu (1994)
[c]Peng et al. (1990)
[d]Zhang and Wang (1991b)
[e]Zhang et al. (1992)
[f]Fang et al. (1986)
[g]Liu et al. (1987)
[h]Wang and Hu (1989)
[i]Wang et al. (1996)
[j]Tang and Zang (1984)
[k]Wu et al. (1994)
[l]Zhang et al. (1996)
[m]Zhou et al. (1992)
[n]Lin and Hao (1989)
[o]Li and Wang (1999)
[p]Yi and Ding (1990)
[q]Wang et al. (1998a)
[r]Wei and Wang (1989)
[s]Wei and Wang (1991)
[t]Xing et al. (2000)

bly by a small number of fungal species that could be identified.

Species richness and community diversity across China

A prerequisite to any study of population structure and diversity is the clarification of the species concept for AMF (Dodd et al. 1996). Based on the lack of sexual reproduction in AMF, it has been suggested that applying the species concept could be difficult and that it would be more appropriate to base the description of biodiversity on genetic diversity (Sanders et al. 1996). However, even for interpretation of the most recent molecular ecological studies, genetic variation within one population and among different isolates of one species can be quite high (Antoniolli et al. 2000; Clapp et al. 2001; Redecker et al. 2003). Morphospecies are units of classical taxonomy and units of experimental manipulation when linking organismal and molecular scales.

About 200 AMF species have so far been discovered worldwide. Despite this low taxonomic diversity for such a widespread group of organisms (Allen et al. 2003), each species may contain considerable genetic diversity. Analysis of local populations adapted to various conditions is therefore essential. A total of 104 AMF species within nine genera have been reported in the rhizosphere of different plant species in various habitats in China since the 1980s and 12 new species were discovered in these surveys (Table 2). Occurrence of AMF genera varies in abundance and frequency across China. *Glomus* species are widely distributed in various habitats and dominate communities in the cold or temperate parts of the north and west, as well as in the tropical and subtropical vegetation in the south and east, of the country. The frequency of occurrence and abundance of sporulation by *Glomus* species are much higher than in other genera. *Acaulospora* is the second most dominant genus in China, ranking after *Glomus* in the north and west and similar to *Glomus* in the south and east. *Gigaspora* and *Scutellospora* species are found mostly in the coastal sand dunes and islands, and have been reported from southern and eastern areas that are near the sea (Wang et al. 2004a). These genera also dominate in the Shandong Peninsula, especially in association with wild plants and in woodlands (Gai et al. 2000a; Wang et al. 2003, 2004a,b). Other genera seem to be less common in China, with only a few examples of species, such as *Paraglomus occultum* and *Entrophospora infrequens*, reported (Zhang et al. 1998b; Gai et al. 2000a).

Frequency of occurrence also varies at the species level. *Glomus mosseae* has been found at almost all sites investigated (90%), associating with a variety of crop and wild plant species in both natural and disturbed soils. *Glomus mosseae* is a dominant species in habitats of northern China, but is found at lower frequencies in habitats of southern China (Table 3). *Acaulospora* species dominate in the latter habitats. The frequency of *G. mosseae* was found to decrease from north to south along the southern and eastern coasts (Zhang et al. 1999). Species richness showed an increasing trend from north to south (Table 3).

Species diversity in natural and disturbed habitats has been compared in several studies (Wang et al. 2003; Zhang et al. 2004b). Results vary with ecological features and histories of the habitats investigated. Wang et al. (2003) compared richness, distribution, and sporulation abundance of AMF species in island forests, saline soils, coal mine spoil heaps, and degraded grasslands. Species richness in natural island forests was much greater than in any of the three disturbed habitats. *Glomus* species were dominant at all sampling sites, but the frequency and relative sporulation by *Acaulospora* species were higher at coal mine spoil sites. *Gigaspora* species sporulated more abundantly than *Acaulospora* species in island forest areas. Zhang et al. (2004b) compared the diversity of AMF

Table 2 AMF reported from different geographical areas of China

AMF	Reference	Habitat and vegetation type
Acaulospora		
Acaulospora bireticulata Rothwell & Trappe	Peng et al. 1990	CS, N, NE/ farmland
Acaulospora cavernata Blaszkowski	Xing et al. 2000	NE/ Panax field
Acaulospora denticulata Sieverding & Toro	Wu et al. 1995a	E/ tea garden with red soil
Acaulospora dilatata Morton	Zhang et al. 1998a	CS, E/ tea garden and cocoa orchard
Acaulospora elegans Trappe & Gerdemann	Peng et al. 1990	SW, CS/ farmland
Acaulospora excavata Ingleby & Gerdemann	Zhang et al. 2001	CS/ aluminum mine site
Acaulospora foveata Trappe & Janos	Wu and Chen 1986	Taiwan / bamboo vegetation
Acaulospora lacunosa Morton	Gai and Liu 2000	E/ wild plants in heathland and upland
Acaulospora laevis Gerdemann & Trappe	Wu and Chen 1986	Taiwan-E/ bamboo vegetation
Acaulospora nicolsonni Walker, Read and Sanders	Fang et al. 2000	CS/ tobacco field
Acaulospora longula Spain & Schenck	Zhang et al. 1992	NW/ wild chrysanthemum at lakeside
Acaulospora mellea Spain & Schenck	Hu 1988	Taiwan/ fir and Taiwania fir
Acaulospora morrowae Spain & Schenck	Hu 1988	Taiwan / fir and Taiwania fir
Acaulospora myriocarpa Spain, Sieverding & Schenck	Hu 1988	Taiwan / fir and Taiwania fir
Acaulospora polonica Blaszkowski	Zhang et al. 2001	CS/ aluminum mine site
Acaulospora rehmii Sieverding & Toro	Shi et al. 2003b	CS/ Dipterocarpaceae at Jianfengling mountain
Acaulospora rugosa Morton	Zhang et al. 1998a	E/ longan orchard
Acaulospora scrobiculata Trappe	Wu and Chen 1986	Taiwan / bamboo vegetation
Acaulospora spinosa Walker & Trappe	Hu 1988	Taiwan-S/ fir and Taiwania fir
Acaulospora taiwania Hu[a]	Hu 1988	Taiwan-S/ fir and Taiwania fir
Acaulospora tuberculata Tanos & Trappe	Zhao and Du 1997	SW/ tropical pteridophytes
Acaulospora undulata Sieverding	Zhang et al. 2001	CS/ aluminum mine site
Archeospora		
Archeospora leptoticha (Schenck & Smith) Morton & Redecker	Hu 1988	Taiwan-S/ fir and Taiwania fir
Archeospora trappei (Ames & Linderman) Morton & Redecker	Wu and Chen 1986	Taiwan-S/ bamboo vegetation
Diversispora		
Diversispora spurca Pfeiffer, Walker & Bloss	Gai et al. 2004	N/ farmland
Entrophospora		
Entrophospora infrequens (Hall) Ames & Schneider	Peng et al. 1990	CS/ farmland
Entrophospora colombiana Spain & Schenck	Zhang et al. 2003b	SW/ subtropical fir
Entrophospora kentinensis Wu & Liu[a]	Wu et al. 1995b	Taiwan / bamboo in highlands
Gigaspora		
Gigaspora albida Walker & Rhodes	Fang et al. 2000	E/ tobacco field
Gigaspora alboaurantiaca[a]	Chou et al. 1991	Taiwan /
Gigaspora decipiens Hall & Abbott	Liu et al. 2002	E/ island forest
Gigaspora gigantea (Nicol.& Gerd.) Gerdemann & Trappe	Wu and Chen 1986	Taiwan / bamboo vegetation
Gigaspora margarita Becker & Hall	Peng et al. 1990	CS, N / farmland
Glomus		
Glomus aggregatum Schenck & Smith	Hu 1988	Taiwan / fir and Taiwania fir
Glomus albidum Walker & Rhodes	Wang and Hu 1989	SC/ cotton field
Glomus ambisporum Smith & Schenck	Wang and Hu 1989	SC/ cotton field
Glomus australe (Berk.) Berch	Zhang et al. 2003b	SW/ subtropical pteridophytes
Glomus caledonium Nicolson & Gerdemann	Wu and Chen 1986	Taiwan / bamboo vegetation
Glomus canadense Trappe & Gerdemann	Shi et al. 2004	CS/ Dipterocarpaceae at Diaoluo mountain
Glomus citricolum Tang & Zang[a]	Tang and Zang 1984	CS/ citrus orchard
Glomus claroideum Schenk & Smith	Peng et al. 1990	SW, CS, N,NE / farmland
Glomus clarum Nicolson & Schenk	Hu 1988	Taiwan/ fir and Taiwania fir
Glomus clavisporum (Trappe) Almeida & Schenck	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus constrictum Trappe	Fang et al. 1986	E/ tobacco field
Glomus convolutum Gerdemann & Trappe	Zhang et al. 2003b	SW/ subtropical pteridophytes
Glomus coremioides (Berk & Broome) Redecker et Morton	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus cunninghamia Hu[a]	Hu 1988	Taiwan/ fir and Taiwania fir
Glomus delhiense Mukerji, Bhattacharjee & Tewari	Liu et al. 2001	E/ tabacco field

Table 2 (continued)

AMF	Reference	Habitat and vegetation type
Glomus diaphanum Morton & Walker	Peng et al. 1990	SW, CS, N/ farmland
Glomus dimorphicum Boyetchko & Tewari	Wang et al. 1998a,b	CS/ Casuarina on beach
Glomus dolichosporum Zhang & Wang[a]	Zhang et al. 1997	E, CS/ mango orchard and eucalypt plantation
Glomus etunicatum Becker & Gerdemann	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus fasciculatum (Thaxter) Gerdemann & Trappe	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus fecundisporum Schenck & Smith	Wang et al. 1998a,b	E/ wild plants in heathland
Glomus formosanum Wu & Chen[a]	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus fulvum (Berk & Broome) Trappe & Gerdemann	Wu et al. 2001	NW/ Taiba Mountain Nature Reserve
Glomus geosporum (Nicol. & Gerd.) Walker	Wang and Hu 1989	CS/ cotton field
Glomus gibbosum Blaszkowski	Zhang et al. 2003b	SW/ subtropical pteridophytes
Glomus globiferum Koske & Walker	Zhang et al. 2003b	SW/ subtropical pteridophytes
Glomus glomerulatum Sieverding	Liu et al. 2001	E/ tobacco field
Glomus heterosporum Smith & Schenck	Zhang et al. 2003b	SW/ subtropical pteridophytes
Glomus hoi Berch & Trappe	Wang and Hu 1989	CS/ cotton field
Glomus intraradices Schenck & Smith	Fang et al. 1986	E/ tobacco field
Glomus invermaium Hall	Wu et al. 2001	NW/ Taiba Mountain Nature Reserve
Glomus lacteum Rose & Trappe	Fang et al. 2000	WS/ tobacco field
Glomus liquidambaris (Wu & Chen) Almeida & Schenck[a]	Wu and Chen 1987	Taiwan / bamboo vegetation
Glomus macrocarpum Tul. & Tul.	Hu 1988	Taiwan / fir and Taiwania fir
Glomus magnicaule Hall	Shi et al. 2003b	CS/ Dipterocarpaceae at Jianfengling mountain
Glomus manihotis Howeler, Sieverding & Schenck	Wu et al. 1994	E/ woodland, farmland and citrus orchard on red soil
Glomus melanosporum Gerdemann & Trappe	Wang and Liu 2002	E/ saline–alkaline soil of Yellow River Delta
Glomus microaggregatum Koske, Gemma & Olexia	Zhang et al. 1996	E/ farmland and heathland
Glomus monosporum Gerdemann & Trappe	Zhao 2000	SW/ tropical or subtropical pteridophytes
Glomus mosseae (Nicol. & Gerd.) Gerdemann & Trappe	Fang et al. 1986	E/ tobacco field
Glomus multicaule Gerdemann & Bakshi	Zhao and Du 1997	SW/ tropical pteridophytes
Glomus pakistanica Iqbal & Bushra	Hu 1988	Taiwan/ fir and Taiwania fir
Glomus pallidum Hall	Peng et al. 1990	SW, CS, N NE / farmland
Glomus pansihalos Berch & Koske	Wang and Liu 2002	E/ saline–alkaline soil of Yellow River Delta
Glomus pustulatum Koske, Friese, Walker & dalpe	Wang and Liu 2002	E/ saline–alkaline soil of Yellow River Delta
Glomus reticulatum Bhattacharjee & Mukerji	Gai et al. 2000b	E/ wild plants in heathland and upland
Glomus rubiforme Gerdemann & Trappe	Wu and Chen 1986	Taiwan/ bamboo vegetation
Glomus sinuosum (Gerd. & Bakshi) Almeida & Schenck	Wang et al. 1992	CS/ *Acacia confusa* nursery
Glomus spinosum Hu[a]	Hu 2002	Taiwan/ fir
Glomus taiwanense (Wu & Chen) Almeida & Schenck[a]	Wu and Chen 1987	Taiwan/ bamboo vegetation
Glomus tenebrosum (Thaxter) Berch	Wang and Liu 2002	E/ saline–alkaline soil of Yellow River Delta
Glomus tortuosum Schenck & Smith	Wu et al. 2000	NW/ fir at Taiba Mountain
Glomus verruculosum Blaszkowski & Tadych	Li et al. 2004	SW/ dry–hot valley of Jinsha River
Glomus versiforme (Karsten) Berch	Zhang and Wang 1991b	N, NE/ farmland and heathland
Glomus viscosum Nicolson	Li et al. 2004	SW/ dry–hot valley of Jinsha River
Pacispora		
Pacispora scintillans (Rose and Trappe) Oehl & Sieverd.	Hu 1988	Taiwan / fir and Taiwania fir
Pacispora chimonobambusae (Wu and Liu) Oehl & Sieverd[a]	Wu et al. 1995b	Taiwan / bamboo in highlands
Paraglomus		
Paraglomus occultum (Walker) Morton & Redecker	Peng et al. 1990	CS, N, NE / farmland
Scutellospora		
Scutellospora auriglоba (Hall) Walker & Sanders	Peng et al. 1990	CS/ farmland
Scutellospora calospora Walker & Sanders	Hu 1988	Taiwan/ fir and Taiwania fir
Scutellospora coralloidea Walker & Sanders	Pan et al. 1997b	NW/ wild plants in the Loess Plateau
Scutellospora erythropa (Nicol.& Gerd.) walker & Sanders	Pan et al. 1997b	NW/ wild plant in the Loess Plateau
Scutellospora fulgida Koske & Walker	Wang et al. 1998a,b	SW/ casuarina at seaside

Table 2 (continued)

AMF	Reference	Habitat and vegetation type
Scutellospora gilmorei (Trappe & Gerd.) Walker & Sanders	Hu 1988	Taiwan/ fir and Taiwania fir
Scutellospora gregaria (Schenck & Nicol.) Walker & Sanders	Zhao 1998	SW/ tropical, subtropical pteridophytes
Scutellospora heterogama (Nicol.& Gerd.) Walker & Sanders	Wu et al. 1994	E/ Citrus orchard, woodland with red soil
Scutellospora nigra (Readhead) Walker & Sanders	Hu 1988	Taiwan/ fir and Taiwania fir
Scutellospora pellucida (Nicol.& Schenck) Walker & Sanders	Hu 1988	Taiwan/ fir and Taiwania fir
Scutellospora persica (Koske & Walker) Walker & Sanders	Zhao 1998	SW/ tropical, subtropical pteridophytes
Scutellospora reticulata (Koske, Miller & Walker) Walker & Sanders	Wang et al. 1998a,b	E/ pot herb
Scutellospora trirubiginopa Pan & Zang[a]	Pan et al. 1997a	NW/ wild plants on Loess Plateau
Scutellospora verrucosa (Koske & Walker) Walker & Sanders	Yang et al. 2004	SW/ *Dodonaea viacosa*

SW southwest China, *CS* central south China, *N* north China, *E* east China, *NW* northwest China, *NE* northeast China
[a]New species described in China

in deforested (Mantoushan) and natural forest (Banruosi) areas in the subtropical region of Dujiangyan, southwest China. They found that *Acaulospora* and *Glomus* were the dominant genera in both regions. The Shannon–Weiner index of AM fungal diversity was higher in the natural forest (2.67) than in the deforested area (2.15). The annual herbaceous plants were assumed to play a major role in maintaining and increasing sporulation and species richness in the deforested area.

Comparisons between different geographical regions

Habitat type is an important factor influencing AMF communities (Stutz et al. 2000). Not surprisingly, AMF have been found in soils of all six geographical zones of China (Table 3). Differences among the ecological zones in the diversity of genera and species are considerable. Unfortunately, there has been no study looking at one plant species across all the zones, and so, comparisons are virtually impossible because different vegetation types were selected in surveys, and soil and climatic conditions in some studies were not clear. However, the overall plant diversity of southeastern areas is much higher than that in the northwest, and it is tempting to suggest that a combination of climatic and plant influences may contribute to the greater diversity of AMF in southern and eastern areas compared with those of the north and west.

Influence of plant taxa

Numerous studies in China have focused on AM fungal communities and their interaction with plant species, especially the types and intensity of mycorrhizal associations in different vegetation types (Peng et al. 1990; Zhang et al. 2004a; Shi et al. 2003b). Because agriculture plays a central role in most rural parts of China, many research groups have focused on field crops or on wild plants in cultivated areas. Gai et al. (2000a, 2004) surveyed the fungal diversity of field crops and wild plants in northern China and found that many more AMF species were associated with wild plants than with field crops. The abundance of sporulation showed the opposite trend. The dominant AMF species also changed. Species in *Gigaspora* and *Scutellospora* were much more frequently associated with wild plants than with field crops. Jansa et al. (2002) observed a similar pattern when comparing the diversity and structure of AMF communities as affected by tillage in a temperate soil. The species composition of AMF in the rhizosphere of pteridophytes, which are thought to have been the earliest examples of AM plants in evolution (Gemma et al. 1992), was investigated in some subtropical and tropical areas in China (Zhao 1998; Zhang et al. 2004a). The dominant fungal genera associated with these plant taxa were *Acaulospora* and *Glomus* at both Dujiangyan in central south China and Xishuangbanna in southwest China. However, AMF species richness and spore abundance differed with the pteridophyte species.

Effect of soil conditions

Soil properties appear to influence the distribution of AMF genera and species, at least based on sporulation patterns (Johnson et al. 1992; Bever et al. 2002). It has been shown in numerous studies that pH is an important factor influencing AM fungal species composition in soils (see, for example, Wang 1985, 1993). Soils are mostly acid in the south of China (pH 5–6), whereas they are calcareous in the north (pH 7–8). *Glomus* appears to dominate in alkaline and neutral soils, while *Acaulospora* sporulates more abundantly in acid soils (Zhang et al. 1998b; Gai and Liu 2003), a pattern that parallels the regional distribution patterns of these genera. Soil type and organic matter content are also likely to influence AMF community composition. In China, AMF communities have been reported to vary between different soil types with, for example, *Acaulospora* species being more frequent in latosols, lateritic red earths, or paddy soils, and *Gigaspora* and *Scutellospora* species being more common in brown soils or paddy soils (Gai and Liu 2003; Zhang et al. 1999). Indications for the probable influence of soil organic matter on the distribution of some AMF species in China come

Table 3 Some regional surveys of AMF in China

Region	Vegetation type	Dominant AM fungal genus	Dominant AM fungal species	No. of samples/ plant spp.	Spore number $20g^{-1}$ soil	Species richness	Reference
I Northeast, II North, V Northwest	Cultivated and wild plants	*Glomus*	Glomus mosseae, *Glomus versiforme*	675 / 35S	–	60[a]/ –[b]	Zhang et al. 1994
II North	Grassland and desert	*Glomus*	*Glomus constrictum*, *Glomus versiforme*	168 / 162S	–	36/ –	Bao et al., unpublished data
III East	Fruit, woodland and crops	*Scutellospora* *Glomus*	*Scutellospora heterogama*, *Glomus manihotis*			18/ –	Wu et al. 1995a
III East, IV Central South	Cultivated and wild plants	*Glomus*	*Glomus mossea*, *Acaulospora mellea*, *Glomus sinuosa*	278 / 60F	38	62/ 3.7	Zhang et al. 1998b, 1999
V Northwest	Semiarid or arid regions	*Glomus*	*Glomus claroideum*, *Glomus intraradices*, *Glomus mosseae*, *Paraglomus occultum*	114 / 45S	78	27/ 2.3 (1–6)	Gai et al., unpublished data
VI Southwest	Tropical forest	*Glomus*, *Acaulospora*	Acaulospora rugosa, *Acaulospora bireticulata* Acaulospora denticulata, *Glomus monosporum*	42 / 42S	96	25/ 4.5 (2–7)	Zhao et al. 2001a
	Wild herbs, shrubs and trees	*Glomus*, *Acaulospora*	*Acaulospora laevis*, *Glomus versiforme*	58 / 58S	42	47/ 3 (1–5)	Zhang et al. 2003a
	Tibetan grassland	*Glomus*	*Glomus mosseae*, *Acaulospora laevis,* *Pacispora scintillans*	71 / 28S	26	33/ 2.5 (1–6)	Gai et al., unpublished data

S species, *F* families, – not reported
[a]Number of AM fungal species at the sampling site
[b]Number of AM fungal species per soil sample

from the observations that, for example, the frequency of occurrence of *G. mosseae* decreased with increasing organic matter content, while *Glomus sinuosum* and *Glomus taiwanense* were found only when soil organic matter content was less than 1.5% (Zhang et al. 1999).

Specialist species in some habitats

AM fungal community structure shows some correspondence with habitat type. For example, some of the most commonly detected species in arid and semiarid zones of north China, such as *G. mosseae*, *Glomus intraradices*, and *Glomus etunicatum* (Zhang et al. 1994; Gai et al., unpublished data), are often also frequent in other arid or semiarid regions in the world (Bloss and Walker 1987; Stutz et al. 2000; Ferrol et al. 2004). The proliferation of small-spore species in the arid or semiarid regions of northwest and northeast China (Gai et al. unpublished data; Li and Zhao, 2005) approximates to similar findings in southwestern North America and Namibia (Stutz et al. 2000). Some AMF species are associated with unique habitats. For example, *Pacispora scintillans* was readily found in regions of high altitude such as Tibet and Xinjiang (Qiao et al. 2005; Gai et al., unpublished data) and was a dominant species in the grasslands of northern Tibet. *Glomus formosanum* was found to occur mainly in subtropical or tropical habitats, with no records from northern China so far (Wu and Chen 1987; Zhang et al. 1998b, 2004a). The phenomenon that some AMF species may prefer particular environments may be ascribed to local ecological factors and to regional ecological history. It has been proposed that environmental conditions may select a suite of AMF species that are available for colonization (Klironomos et al. 2001; Stutz et al. 2000), resulting in genetic diversity being limited to a particular species or genera in habitats with similar environmental conditions.

AMF germplasm collections

Efforts to develop germplasm collections of AMF in China have intensified in recent years. The Chinese Bank of Glomeromycota at the Beijing Academy of Agricultural and Forestry Science is the largest germplasm bank on the mainland, in which 56 isolates corresponding to 11 species from China are stored. Some of Chinese isolates have been registered in international banks: 50 are registered in the International Bank for the Glomeromycota (IBG) (http://www.kent.ac.uk/bio/beg/), and five in the International Culture Collection of Arbuscular and Vesicular–Arbuscular Mycorrhizal Fungi (http://www.invam.caf.wvu.edu/). A Chinese Arbuscular Mycorrhizal Fungal database link with the IBG has also been set up (http://www.acad.polyu.edu.hk/~bccamf/) within the framework of a European project (http://www.dijon.inra.fr/mychintec/). In addition, collections of AMF germplasm continue to be maintained by various mycorrhizal research groups, for example, at the National Dong Hwa University in Taiwan, China Agricultural University in Beijing, and Huazhong Agricultural University in Wuhan.

Future challenges

Much research has been devoted to identifying mycorrhizal associations in diverse plant communities, characterizing fungal communities, and understanding the distribution patterns of AMF in different habitats in China. However, the mycorrhizal status and pattern of fungal diversity in some plant taxa and habitats remain poorly understood. Large-scale surveys across different ecological zones, including studies of AMF associated with single plant species, should be conducted with standard methods to allow broad comparisons and to address questions about biogeography on a continental scale. Chinese researchers envisage such pioneering studies in the near future.

The taxonomy of the Glomeromycota is presently in considerable flux, with conflicting morphological and molecular data sets, and the phylum for AMF has recently been revised several times (Morton and Redecker 2001; Schüßler et al. 2001; Walker and Schüßler 2004). Phylogenetic analysis for classification must be resolved using additional criteria that extend beyond morphology and ribosomal encoding genes. It is therefore important and urgent for Chinese scientists to also utilize and expand on new molecular tools to explore both classification and distribution of AMF species within roots and in soils.

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References

Allen MF, Swenson W, Querejeta JI, Egerton-Warburton LM, Treseder KK (2003) Ecology of mycorrhizae: a conceptual framework for complex interactions among plants and fungi. Annu Rev Phytopath 41:271–303

Antoniolli ZI, Schachtman DP, Ophel-Keller K, Smith SE (2000) Variation in rDNA its sequences in *Glomus mosseae* and *Gigaspora margarita* spores from a permanent pasture. Mycol Res 104:708–715

Bao YY, Yan W (2004) Arbuscular mycorrhizae and their structural types on common plants in grasslands of midwestern Inner Mongolia. Biodivers Sci 12:501–508

Barrow JR, Havstad KM, McCaslin BD (1997) Fungal root endophytes in fourwing saltbush, *Atriplex canescens*, on arid rangelands of southwestern USA. Arid Soil Res Rehabil 11:177–185

Bever JD, Schultz PA, Pringle A, Morton JB (2002) Arbuscular mycorrhizal fungi: more diverse than meets the eye, and the ecological tale of why. Bioscience 51:923–931

Bloss HE, Walker C (1987) Some endogonaceous mycorrhizal fungi of the Santa Catalina mountains in Arizona. Mycologia 79: 649–654

Chen X, Fang ZG, Tang JJ (2001) Investigation on host plants of vesicular arbuscular mycorrhizal fungi (VAMF) within weed communities in agricultural slope land in the red soil area of southeastern China. Biodivers Sci 9:122–128

Chou WN, Yen CH, Chung HH (1991) Species of *Gigaspora* and *Scutellospora* (Endogonaceae) in Taiwan. Trans Mycol Soc Rep China 6:3

Clapp JP, Rodriguez RA, Dodd JC (2001) Inter- and intra-isolate rRNA large subunit variation in *Glomus coronatum* spores. New Phytol 149:539–554

Ding Q, Jia GX, Jiang HB (2004) A survey of arbuscular mycorrhiza of wild flowers in Longtou Mountain area and its application. J Beijing For Univ 26:51–54

Dodd JC, Rosendahl S, Giovannetti M, Broome A, Lanfranco L, Walker C (1996) Inter- and intraspecific variation within the morphologically similar arbuscular mycorrhizal fungi *Glomus mosseae* and *Glomus coronatum*. New Phytol 133:113–122

Fang YC, Liu YR, Fang R (1986) The isolation and identification of endomycorrhizal fungi on tobacco. Acta Mycol Sinica 5: 185–190

Fang YC, Huang Z, Liu YR (2000) Study on VA mycorrhizal flora of tobacco (Nicotiana tobacum). Acta Tob Sinica 6:26–31

Ferrol N, Calvente R, Cano C, Barea JM, Azcón-Aguilar C (2004) Analysing arbuscular mycorrhizal fungal diversity in shrub-associated resource islands from a desertification threatened semiarid Mediterranean ecosystem. Appl Soil Ecol 25:123–133

Gai JP, Liu RJ (2000) Arbuscular mycorrhizal fungi on wild plants. Mycosystema 19:24–28

Gai JP, Liu RJ (2003) Effect of soil factors on AMF in the rhizosphere of wild plants. Chin J Appl Ecol 14:470–472

Gai JP, Liu RJ, Li XL (2000a) Ecological distribution of arbuscular mycorrhizal fungi on wild plants in different vegetation regions of Shandong Province. Chin J Ecol 19:18–22

Gai JP, Liu RJ, Meng XX (2000b) Arbuscular mycorrhizal fungi on wild plants. Mycosystema 19:205–211

Gai JP, Feng G, Li XL (2004) Diversity of arbuscular mycorrhizal fungi in field soils from North China. Biodivers Sci 12: 435–440

Gai JP, Cai XB, Feng G, Christie P, Li XL (2005) Arbuscular mycorrhizal fungi associated with sedges on the Tibetan plateau. Mycorrhiza DOI: 10.1007/s00572-005-0031-8

Gemma JN, Koske RE, Flynn T (1992) Mycorrhizae in Hawaiian pteridophytes: occurrence and evolutionary significance. Am J Bot 79:843–852

Gong MQ, Chen YL, Zhong CL (1997) Mycorrhizal research and application. China Forestry Publishing House, Beijing, p 223

Haselwandter K (1987) Mycorrhizal infection and its possible ecological significance in climatically and nutritionally stressed alpine plant communities. Angew Bot 61:107–114

Haselwandter K, Read DJ (1980) Fungal associations of roots of dominant and sub-dominant plants in high-alpine vegetation systems with special reference to mycorrhiza. Oecologia 45: 57–62

Hu HT (1988) Study on the endomycorrhizae of Chinese fir (*Cunninghamia lanceolata* Hooker) and Taiwania (*Taiwania-cryptomerioides* Hay.). Q J Chin For 21:45–72

Hu HT (2002) *Glomus spinosum* sp. nov. in the Glomaceae from Taiwan. Mycotaxon 83:159–164

Ingham ER, Wilson MV (1999) The mycorrhizal colonization of six wetland plant species at sites differing in land use history. Mycorrhiza 9:233–235

Janos DP (1980) Vesicular-arbuscular mycorrhizae affect lowland tropical rain forest plant growth. Ecology 61:151–162

Jansa J, Mozafar A, Anken T, Ruh R, Sanders IR, Frossard E (2002) Diversity and structure of AMF communities as affected by tillage in a temperate soil. Mycorrhiza 12:225–234

Johnson NC, Tilman D, Wedin D (1992) Plant and soil controls on mycorrhizal fungal communities. Ecology 73:2034–2042

Klironomos JN, Hart MM, Gurney JE, Moutoglis P (2001) Interspecific differences in the tolerance of arbuscular mycorrhizal fungi to freezing and drying. Can J Bot 79:1161–1166

Li Y, Wang B (1999) A preliminary report on the VA mycorrhizal fungi infecting *Mimosa padica*. J Xian United Univ 2:32–34

Li T, Zhao ZW (2005) Arbuscular mycorrhizas in a hot and arid ecosystem in southwest China. Appl Soil Ecol 29:135–141

Li T, Li JP, Zhao ZW (2004) Two new records of arbuscular mycorrhizal fungi in China. Mycosystema 23:144–145

Lin XG, Hao WY (1989) The dependency of different plants on vesicular–arbuscular mycorrhizal fungi. Acta Bot Sinica 31: 721–725

Liu RJ, Xue BY, Huang Z (1987) Investigation of vesicular–arbuscular (VA) mycorrhiza in the fruit of Shandong Province. J Shandong Agric Univ 18:25–31

Liu YR, Fang YC, Huang Z (2001) Isolation and identification of vesicular arbuscular mycorrhizal fungi in the tobacco culture area in Shandong province. J Jilin Agric Univ 23:40–45

Liu RJ, Wang FY, Meng XX (2002) Arbuscular mycorrhizal fungi on the islands of Bohai Bay. Mycosystema 21:525–532

Morton JB, Redecker D (2001) Two new families of Glomales, Archaeosporaceae and Paraglomaceae, with two new genera *Archaeospora* and *Paraglomus*, based on concordant molecular and morphological characters. Mycologia 93:181–195

Muthukumar T, Udaiyan K (2000) Arbuscular mycorrhizas of plants growing in the Western Ghats region, southern India. Mycorrhiza 9:297–313

Muthukumar T, Sha LQ, Yang XD, Cao M, Tang JW, Zheng Z (2003) Mycorrhiza of plants in different vegetation types in tropical ecosystems of Xishuangbanna, southwest China. Mycorrhiza 13:289–297

Muthukumar T, Udaiyan K, Shanmughavel P (2004) Mycorrhiza in sedges: an overview. Mycorrhiza 14:65–77

Newman EI, Reddell P (1987) The distribution of mycorrhizas among families of vascular plants. New Phytol 106:745–751

Niu JQ (1994) A survey of vesicular–arbuscular mycorrhiza in Guangdong province and its application study. Acta Pedol Sinica 31:54–63

O'Connor PJ, Smith SE, Smith AF (2002) Arbuscular mycorrhizas influence plant diversity and community structure in a semiarid herbland. New Phytol 154:209–218

Pan XL, Zhang GY, Wang YJ, Wu SJ (1997a) A new VAM species from the loess plateau, *Scutellospora trirubiginopa*. Mycosystema 16:169–171

Pan XL, Zhang GY, Wang YJ, Wu SJ (1997b) VAMF species of the loess plateau IV. Mycosystema 16:166–168

Peng SB, Shen CY, Chiu WF (1990) Some Endogonaceae mycorrhizal fungi from China. Acta Mycol Sinica 9:169–175

Qiao HQ, Zhang Y, Guo LD, Fu JF (2005) Arbuscular mycorrhizal fungi associated with the most common plants in north Xinjiang. Mycosystema 24:130–136

Redecker D, Hijri I, Wiemken A (2003) Molecular identification of arbuscular mycorrhizal fungi in roots: perspectives and problems. Folia Geobot 38:113–124

Rickerl DH, Sancho FO, Ananth S (1994) Vesicular–arbuscular endomycorrhizal colonization of wetland plants. J Environ Qual 23:913–916

Sanders IR, Clapp JP, Wiemken A (1996) The genetic diversity of arbuscular mycorrhizal fungi in natural ecosystems: a key to understanding the ecology and functioning of the mycorrhizal symbiosis. New Phytol 133:123–134

Schüßler A, Schwarzott D, Walker C (2001) A new fungal phylum, the Glomeromycota: phylogeny and evolution. Mycol Res 105: 1413–1421

Shi ZY, Chen YL, Liu RJ (2003a) Arbuscular mycorrhizal fungi of Dipterocarpaceae in Xishuangbanna, southern Yunnan. Mycosystema 22:402–409

Shi ZY, Chen YL, Liu RJ (2003b) Arbuscular mycorrhizal fungi of Dipterocarpaceae on Jianfengling Mountain, Hainan Province. Mycosystema 22:211–215

Shi ZY, Chen YL, Liu RJ (2004) A new species record of arbuscular mycorrhizal fungi in China. Mycosystema 23:312

Smith SE, Read DJ (1997) Mycorrhizal symbiosis, 2nd edn. Academic Press, London, p 605

Stutz JC, Copeman R, Martin CA, Morton JB (2000) Patterns of species composition and distribution of arbuscular mycorrhizal fungi in arid regions of southwestern North America and Namibia, Africa. Can J Bot 78:237–245

Tang ZY (1977) Citrus mycorrhiza. Citrus Sci Technol 3:73

Tang ZJ, Zang M (1984) A supplement to the manual of Endogonaceae and a new species, *Glomus citricolum*. Acta Bot Yunnanica 6:295–304

Tester M, Smith SE, Smith FA (1987) The phenomenon of 'nonmycorrhizal' plants. Can J Bot 65:419–431

Trappe JM (1987) Phylogenetic and ecologic aspects of mycotrophy in the angiosperms from an evolutionary standpoint. In: Safir GR (ed) Ecophysiology of VA mycorrhizal plants. CRC Press, Boca Raton, pp 5–26

Walker C, Schüßler A (2004) Nomenclatural clarifications and new taxa in the Glomeromycota. Mycol Res 108:979–982

Wang GM (1985) Soil pH and vesicular–arbuscular mycorrhizas. In: Fitter AH (ed) Ecological interactions in soil. Blackwell, Oxford, pp 219–224

Wang GM (1993) Effect of pH on arbuscular mycorrhiza. I. Field observation on the long term liming experiments at Rothamsted and Woburn. New Phytol 124:465–472

Wang P, Hu ZJ (1989) The isolation and identification of vesicular–arbuscular mycorrhizal fungi on cotton. J Huazhong Agric Univ 8:36–44

Wang FY, Liu RJ (2002) Arbuscular mycorrhizal fungi in saline–alkaline soils of the Yellow River Delta. Mycosystema 21: 196–202

Wang HG, Wu GY, Li HQ (1992) Discovery of a species — *Sclerocystis sinuosa* — on Endogonaceae in China. Acta Mycol Sinica 11:78–79

Wang YS, Zhang MQ, Xing LJ, Wang KN (1996) VA mycorrhizal fungi from the south and east coasts of China. I. Four species of *Sclerocystis*. Acta Mycol Sinica 15:161–165

Wang Q, Li HQ, Du YR, Lin Y, Li HW (1998a) Isolation and identification of VA mycorrhizal fungi on *Radix gentianae*. Biotechnology 8:19–22

Wang YS, Zhang MQ, Wang KN, Xing LJ (1998b) VA mycorrhizal fungi of the south and east coasts of China IV, four new records. Mycosystema 17:301–303

Wang FY, Liu RJ, Lin XG, Zhou JM (2003) Comparison of diversity of arbuscular mycorrhizal fungi in different ecological environments. Acta Ecol Sinica 23:2666–2671

Wang FY, Lin XG, Zhou JM (2004a) Biodiversity of AMF in China. Chin J Ecol 23:149–154

Wang MY, Diao ZK, Liu RJ (2004b) Taxonomic characteristics and distribution of species and genera in Gigasporaceae of AMF. J Fungal Res 2:6–11

Wu CG, Chen ZC (1986) The Endogonaceae of Taiwan. I. A preliminary investigation on Endogonaceae of bamboo vegetation at Chitou areas, central Taiwan. Taiwania 31:65–87

Wu CG, Chen ZC (1987) The Endogonaceae of Taiwan. II. Two new species of *Sclerocystis* from Taiwan. Trans Mycol Soc Rep China 2:73–83

Wu TH, Hao WY, Lin XG, Shi YQ (1994) Two new records of VA mycorrhizal fungi from China. Acta Mycol Sinica 13:310–311

Wu TH, Hao WY, Lin XG, Shi YQ (1995a) VA mycorrhizal fungi (Glomales) and their ecological distribution in red soils. Acta Mycol Sinica 14:81–85

Wu CG, Liu YS, Hwuang L (1995b) Glomales of Taiwan. V. *Glomus chimonobambusae* and *Entrophospora kentinesis* spp. nov. Mycotaxon 53:283–294

Wu CH, Tang M, Ma YS, Li XL (2000) Five species of AMF from the rhizal soil of *Abies fargesii* Franch forest in Taibai Mountain Reserve. J Northwest For Univ 15:49–52

Wu CH, Wang JR, Yang JX, Liu LH (2001) A study on the resources of AMF in Taibai Mountain Nature Preserve. J Northwest For Univ 16:35–39

Xing XK, Li Y, Dalpe Y (2000) Ten species of VAMF in five ginseng fields of Jilin province. J Jilin Agric Univ 22:41–46

Yang L, Wang GH, Ren LC, Zhao ZW (2002) Arbuscular mycorrhizae of the family Amaranthaceae. Acta Bot Yunnanica 24:37–40

Yang AN, Li LF, Zhao ZW (2004) A new record species of arbuscular mycorrhizal fungi in China. Mycosystema 23:603–604

Yi WM, Ding MM (1990) A preliminary survey of vesicular–arbuscular mycorrhiza associated with common plants in the plantations at Heshan and Dianbai, Guangdong Province. Trop Subtrop For Ecosyst 7:41–50

Zhang MQ, Wang YS (1991a) A key to the species in *Glomus*. Microbiology 18:367–371

Zhang MQ, Wang YS (1991b) Seven species of VA mycorrhizal fungi from northern China. Acta Mycol Sinica 10:13–21

Zhang MQ, Wang YS, Huang L (1992) Eight species of VA mycorrhizal fungi from northern China. Acta Mycol Sinica 11:258–267

Zhang MQ, Wang YS, Zhang C, Huang L (1994) The ecological distribution characteristics of some genera and species of VAMF in northern China. Acta Mycol Sinica 13:166–172

Zhang MQ, Wang YS, Wang KN, Xing LJ (1996) The VA mycorrhizal fungi of the southeast coastal areas of China. II. Four species of *Glomus*. Mycosystema 15:241–246

Zhang MQ, Wang YS, Xing LJ (1997) *Glomus dolichosporum*, a new species of Glomales from southern China. Mycosystema 16:241–243

Zhang MQ, Wang YS, Wang KN, Xing LJ (1998a) VA mycorrhizal fungi of the south and east coasts of China, seven new records of *Acaulospora*. Mycosystema 17:15–18

Zhang MQ, Wang YS, Xing LJ (1998b) The ecological distribution of AM fungal communities in the south and east coasts of China. Mycosystema 17:274–277

Zhang MQ, Wang YS, Xing LJ (1999) The regional distribution of AMF in the south and east coasts of China. Mycosystema 18:145–148

Zhang MQ, Wang YS, Xing LJ, Zhang WM, Ma YQ, Li XP (2001) Three new records of *Acaulospora* from an aluminum mine field in Guangxi province in China. Mycosystema 20:271–272

Zhang Y, Guo LD, Liu RJ (2003a) Diversity and ecology of arbuscular mycorrhizal fungi in Dujiangyan. Acta Phytoecol Sinica 27:537–544

Zhang Y, Guo LD, Liu RJ (2003b) Arbuscular mycorrhizal fungi associated with the most common plants in the subtropical region of Dujiangyan. Mycosystema 22:204–210

Zhang Y, Guo LD, Liu RJ (2004a) Arbuscular mycorrhizal fungi associated with common pteridophytes in Dujiangyan, southwest China. Mycorrhiza 14:25–30

Zhang Y, Guo LD, Liu RJ (2004b) Survey of arbuscular mycorrhizal fungi in deforested and natural forest land in the subtropical region of Dujiangyan, southwest China. Plant Soil 261: 257–263

Zhao ZW (1998) VA mycorrhizal fungi in the rhizosphere soil of tropical and subtropical pteridophytes in Yunnan. Acta Bot Yunnanica 20:183–192

Zhao ZW (2000) The arbuscular mycorrhizas of pteridophytes in Yunnan, southwest China: evolutionary interpretations. Mycorrhiza 10:145–149

Zhao ZW, Du G (1997) Six species of VA mycorrhizal fungi from the rhizosphere of pteridophytes in Yunnan. Mycosystema 16:208–211

Zhao ZW, Li XW, Wang GH, Cheng LZ, Sha T, Yang L, Ren LC (2001a) AMF in the tropical rain forest of Xishuangbanna. Mycosystema 20:316–323

Zhao ZW, Qin XZ, Li XW, Cheng LZ, Sha T, Wang GH (2001b) Arbuscular mycorrhizal status of plants and the spore density of arbuscular mycorrhizal fungi in the tropical rain forest of Xishuangbanna, southwest China. Mycorrhiza 11:159–162

Zhao ZW, Ren LC, Li T, Li JP (2003) Arbuscular mycorrhizas in the dry hot valley of Jinsha River. Acta Bot Yunnanica 25:199–204