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RESEARCH ON DIVERSITY AND COMMUNITY COMPOSITION OF ARBUSCULAR MYCORRHIZAL FUNGI SPECIES IN INDIA: A REVIEW

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Abstract

Arbuscular mycorrhizal fungi (AMF) are endomycorrhizal fungi belonging to the group Glomeromycota. It is a fungus that is ubiquitously found in almost 80% of vascular plant species. AMF has gain significance in recent years because of their role in soil fertility, nutrient uptake, biocontrol of plant diseases and growth of plants. The diversity and community composition of AMF in different ecosystems and plant communities in India have received increasing interest over the past few decades. Many researchers have surveyed AMF colonization and its diversity from different plant groups ranging from angiosperms, gymnosperms, pteridophytes and bryophtes. AMF species belonging to various genera have been reported from environments such as croplands, grasslands, forests, fallow sites, etc. In this paper, we review the works on AMF community composition and diversity, it's functional and genetic diversity, the mycorrhizal status of plants, the biotic and abiotic factors governing AMF diversity, records of AMF species collected from India over the past few decades. Futuristic trends in the study of the biodiversity of AMF are also briefly discussed.

Key words: Arbuscular mycorrhizal fungi, community composition, diversity, species richness.

Introduction

Arbuscular mycorrhizal fungi (AMF) are a group of fungi which are associated with the majority of plant families in different ecosystems around the world ranging from tropics (Janos 1980; Zhao *et al.*, 2001) or arctic-alpine habitats (Haselwandter, 1987) to mesic (Ingham and Wilson, 1999; Muthukumar and Udaiyan, 2000) and arid habitats (Stutz *et al.,* 2000; O'Connor *et al.,* 2002). India is very diverse in the sense that it has a wide range of climatic conditions and soil types, resulting indifferent variety of ecosystems and vegetation structures throughout various geographical locations in India. The studies on AMF started in India relatively late compared to other parts of the world, such as Europe, China, etc. The main theme of early research on AMF in India was based on the mycorrhizal status of plants: the degree of root colonization and spore counts in the field. The study was mostly taxonomical using standard manuals for identification such as that of Schenck and Perez, (1990), Gerdemann and Trappe, (1974); Morton and Benny, (1990). This led to an increase in the identification of AMF within India. Identification of AMF is important for a number of reasons, which include: (i) understanding the phenotypic diversity of AMF in different ecosystems such as natural, managed and disturbed ecosystems; (ii) assessing the competitive abilities of isolates in plant growth promotion activity; (iii) studying the physiological, molecular and bio-chemical phenomenon in mycorrhiza; and (iv) maintaining adequate quality control and purity of commercial inoculum. AMF identification has always posed problems for taxonomists (Morton, 1993; Mehrotra, 1997) as these fungi cannot be cultured on artificial media, which is essential for minimizing the effect of abiotic and biotic factors on the morphological characteristics and also because there has been no report of sexual reproduction in them. The clarification of species concept is a prerequisite for any study on population structure and diversity of AMF (Dodd *et al.,* 1996) and because of the absence of sexual reproduction in AMF it has been suggested by Sanders *et al.,* (1996), that applying the species concept might just not be feasible and that it would make more sense to base the description of biodiversity of AMF on genetic diversity. Around 230-300 AMF species have so far been discovered worldwide (Schüßler and Walker, 2010; Öpik *et al.,* 2013; Oehl *et al.,* 2014). Despite this low taxonomic diversity for such a widespread group of organisms, each species may contain considerable genetic diversity (Allen *et al.,* 2003).

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Therefore, analysis of local population adapted to various conditions is essential. The key features in the life cycle of AMF are spore germination, pre-symbiotic mycelia, growth phase, differential hyphal branching, appressorium formation, root colonization and arbuscule development (Giovannetti *et al.,* 1994). Root colonization differs considerably among AMF and some studies have been done to understand the taxonomic basis for such variations in the colonization strategy of AMF, for example, Hart and Reader, (2004) found that most Glomaceae isolates colonized roots before Acaulosporaceae and Gigasporaceae isolates. They also observed that Glomaceae isolates had high root colonization but low soil colonization, Gigasporaceae isolates showed the opposite trend, whereas Acaulosporaceae had low root and soil colonization. The anatomy of AM differs with the host-endophyte combinations or with certain soil conditions. However, Abbott and Robson, (1991) suggested that the anatomy of AM fungus infecting different hosts remain the same and this feature could be used as additional taxonomic criteria for identification of AMF. Two anatomical types of root colonization viz. (i) Arum-type, defined on the basis of an extensive intercellular phase of hyphal growth in the root cortex and development of terminal arbuscules on intracellular hyphal branches and (ii) Paris-type, defined by the absence of intercellular phase and presence of extensive intracellular hyphal coils, have been described to discriminate between the anatomical structures at the genus level.

Genetic Diversity in Amf

Assessment of genetic diversity of AM association has been far more difficult due to an elementary understanding of the genetics of AMF (Kuhn *et al.,* 2001). Cells of AMF contain 1500-5000 nuclei and we are still not certain whether the nuclei in the cells remain genetically similar (homokaryotic) or dissimilar (heterokaryotic) throughout the existence of the cell (Pawlowska *et al.,* 2004). Hyphal anastomosis in AM serves as a means to maintain diversity through the exchange of genetic material (Giovannetti *et al.,* 2001). Intra-specific AMF species variability also poses practical problems in using molecular tools for the detection of species and strains from field soil (Sanders *et al.,* 1995). Intra-specific diversity has been revealed in *Glomus mosseae* by total protein profiles and ITS-RFLP profiles (Giovannetti *et al.,* 2003) and using rDNA-ITS sequence (Antoniolli *et al.,* 2000). Phenotypic variations in spores of *Enterophospora colombiana* (Mehrotra, 1998), *Scutellospora sinuosa* (Muthukumar *et al.,* 2000) and *Scutellospora pellucida* (Bever *et al.,* 2001) have been reported in some studies. High genetic and phenotypic variation among the isolates of a population of *Glomus intraradices* has also been noted (Koch *et al.,* 2004). Taxon-specific PCRprimers can be used to amplify fungal DNA from AMF mycelial tips (Di Bonito *et al.,* 1995; Reddy *et al.,* 2005) and this approach is now being used to compare fungal diversity from different roots and soil environments. Real-time PCR could be of great help in quantifying a single isolate of AMF in root segments and could offer the opportunity for direct and specific quantification of selected taxa (Alkan *et al.,* 2004) but scaling-up the sampling for root and soil communities will require improved techniques for isolation of DNA and the design for multiple and nested primers procedures (Graham and Miller, 2005).

Assessment of Amf Diversity:

Different plant species cause the buildup of diverse populations of AMF in the soil. AMF are non-specific in its ability to associate with plants. The species richness is related to higher species diversity, a higher degree of ecosystem uniqueness and lower levels of disturbance. Most information about the dynamics and diversity of AMF in field soils is derived from studies of the abundance and types of spores or of the total length of mycorrhizal root infected. Spore population appears to be governed by several interacting factors; among them are soil nutrients and texture, moisture, host plant genotype, plant cover, etc. The quantitative and qualitative composition of spore populations of AMF results from the complex interactions among fungus, plant and its habitat. Also, spore numbers can reflect the relative importance of individual AMF species within populations, but this cannot necessarily be related to their infectivity (Dodd *et al.,* 1990), as fungi sporulate in response to nutrient limitation or other stresses. There are several methods used to isolate spores of AMF from field soil, which include wet sieving and decanting (Gerdemann and Nicolson, 1963), floatation adhesion (Sutton and Barron, 1972), air stream fractionation (Tornmerup, 1982), water-sucrose centrifugation (Ianson and Allen, 1986) and fixing soil slurries to filter paper (Khalil *et al.,* 1994). Addition of 0.0818M sodium hexametaphosphate to soil solution has been found to substantially increase the total number of spores recovered, particularly in heavier soils (Mckenney and Lindsey, 1987). Assessment of AMF species in field soils is not easy because it is mainly based on spore wall characteristics (Walker, 1986) and spores are present at different stages of development (Morton, 1995). Douds and Millner, (1999) have questioned the use of traditionaltaxonomic identification of spores for describing AMF diversity due to the following limitations: (i) the relative abundance of spores of a species may not be indicative of the relative amount of colonization of roots by the fungus or the amount and distribution of hyphae in the soil, non-sporulating species may be present. (ii) a fungus may be a significant member of the vegetative community, but because of date of sampling, local environment or host plant regulation of carbon expenditure, be unable toproduce spores yet be well able to persist to the following year as infective hyphae in roots or soil, (iii) degradation of spore wall can be a great problem in identifying the spores collected from the field. One of the major limitations of direct field assessment of AMF is the low level of spores that can be collected. Further, spores of some species can be absent at the time of sampling, even though they may be present within roots. Mehrotra, (1996), observed that the spores of *Scutellospora calospora*, which were absent in the rhizosphere soils of *Derris indica* formed spores in mycorrhizal pots of *Cassia siamea*, inoculated with the rhizosphere soil of *Derris indica*. Chaurasia *et al.*, (2005), also observed that spores of *Glomus pustulatum*, which were not detected in the rhizosphere soil were recovered from the trap culture, whereas spores of *Gigaspora* spp. present in the rhizosphere soil did not appear in the trap culture. The absence of spores of an AMF species, therefore, does not necessarily indicate its absence in the community. Repeated field collections or the establishment of successive trap cultures (Stutz *et al.*, 2000) can greatly improve the assessment of species composition in natural ecosystems. The depth of sampling is also one of the important factors, which may influence the assessment of species composition and richness. An *et al.*, (1990), suggested that it is necessary to take a soil sample from more than 15 cm depth from the surface because some species are more abundant deeper in the soil profile. Whereas, the general consensus among researchers is that taking a sample from more than 15cm soil depth decreases the AMF population of many species. It is suggested that it might be due to less organic content (Oehl *et al.*, 2005) and low availability of oxygen in deeper soil zones (Verma *et al.*, 2010) because fungi are sensitive to low oxygen pressure which prevails at depth (Brady and Weil, 2008). According to Anderson *et al.*, (1987), AMF is generally scarce where the plant roots are sparse. Thus, the reduction in AMF spore population with increasing soil depth can also be attributed to fewer roots in deeper soil layers (Cuenca and Lovera, 2010). Prasad, (2005) studied the occurrence of AMF at 4 soil depths viz., 13, 15, 23 and 30 cm in non-cultivated, disturbed and non-fertile soils of Bettiah, Bihar and found that the highest number of spores of *Glomus fasciculatum*, *Glomus aggregatum*, *Glomus mosseae*, *Glomus constrictum*, *Glomus intraradices*, *Acaulospora tuberculata*, *Acaulospora laevis*, *Gigapsora* sp. and *Sclerocystis* sp. were present at a depth of 15cm, followed by 8, 23 and 30cm.

Mycorrhizal Status of Plants in India

Trappe, (1987), indicates that while AMF have been recorded in all angiospermic orders examined, information is available for only about 3% of the known plant species. Research work in India on the mycorrhizal status of plants is in its nascent stage and is far from achieving its full potential yet many researchers have conducted investigations on the mycorrhizal status of plants varying from commonly cultivated to wild plants and from varying habitats such as agricultural fields, jhum fallow sites, tea gardens, home gardens, forests, semi-degraded forests, ramsar sites etc. from different geographical regions of India. Although most reports are from Southern India which consists of five states, *i.e.* Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu as well as the union territories of Puducherry, Lakshadweep and Andaman and Nicobar Islands. Of the 329-plant species (representing 61 families) examined in Western Ghats region of Southern Indiaby Muthukumar and Udaiyan, (2000), 174 were mycorrhizal. Out of them, AMF association was recorded in 81 plant species for the first-time including species from several families assumed to be non-mycorrhizal, e.g. Amaranthaceae, Capparaceae, Commelinaceae, Cyperaceae and Portulacaceae. AMF spores of 35 species belonging to genus *Acaulospora*, *Gigaspora*, *Glomus*, *Sclerocystis* and *Scutellospora* were recorded. Another report of plants with AMF association came from Western Ghats of Karnataka region where 46 medicinal plant species were investigated by Rajkumar *et al.*, (2012). All of the surveyed species were mycorrhizal. A total of 36 AMF species were identified. Among the identified AMF taxa, *Glomus* species were found to be dominant followed by *Acaulospora* sps, *Gigaspora* sps, *Scutellospora* sps, *Paraglomus* sps and *Pacispora* sps. AMF association have also been reported from cryptogams such as some Pteridophytes which are of ancient origin (Gemma *et al.*, 1992). Muthukumar *et al.*, (2014), assessed AMF association in 57 different species of pteridophytes occurring in Palani hills of Western Ghats, Southern India. 55 out of 57 (91.66%) ferns examined had AMF association. In yet another report from Valaparai hills, Western Ghats of Tamil Nadu by Santhoshkumar and Nagarajan, (2014), 12 pteridophytic plants investigated for AMF association were all found to be mycorrhizal. The result showed that the mycorrhizal populations such as that of *Glomus* species were found to be dominant, followed by *Acaulospora*, *Sclerocystis, Entrophospora and Gigaspora*. The maximum spore population was found in the rhizosphere of *Adiantum capillus-veneris* belonging to the family *Adiantaceae* while the highest AM fungal infection was reported in the roots of *Angiopteris evecta* belonging to the family *Angiopteridaceae*. Investigations on the prevalence of AMF symbioses are limited for plants growing in tropical, aquatic and wetl and habitats compared to those growing on terrestrial, moist or dry habitats. Kumar and Muthukumar, (2014) examined AMF symbiosis in 8 hydrophytes and 50 wetland plants from 4 sites in South India, the results showed the presence of AMF association in 21 plant species. AMF symbioses were reported for the first time in seven plant species belonging to the family of Asteraceae, Commenlinaceae, Poaceae, Scrophulariaceae and Tiliaceae. Plants with AMF association have also been reported in relatively large numbers from the different land use systems in the North-eastern states of India (Songachan and Kayang, 2011b, Bordoloi *et al.,* 2015; Choudhury *et al.*, 2010; Sharmah and Jha, 2014; Das and Kayang, 2010). Studiesin the moderately degraded sub-tropical forest strands of Meghalaya on 8 plant species for the formation of AMF association showed that, all of the investigated plant species had AMF colonisation. Another survey for AMF diversity was also done in Goa, which is a part of western India by D'Souza and Rodrigues, (2013), in which 17 mangrove species belonging to 8 families present at seven riverine and fringe habitats were investigated for AMF colonization. 16 out of the 17 investigated plants were found to be mycorrhizal. In total 28 AMF species of 5 genera viz. *Glomus, Acaulospora, Scutellospora, Gigaspora* and *Entrophosphora* were recovered from this site. Economically beneficial plants in which high and diverse occurrence of AMF have been noted include medicinal plants (Abdul-Khaliq and Janardhanan, 1994; Bukhari *et al.,* 2003; Muthukumar and Udaiyan 2006), fruit plants (Hasan and Khan, 2005; Kumar *et al.,* 2015; Suresh and Nelson, 2015) and xerophytic plants (Singh and Varma, 1981). In a report from Gwalior-Chambal region, Madhya Pradesh, plant species collected randomly from their habitats spread over 54 families show dominantly polysporal association of AMF (Koul *et al.,* 2012). Some plant families are still believed to never or rarely form mycorrhizal associations due to lack of scientific evidence (Newman and Reddell, 1987; Tester *et al.,* 1987) for example members of the family Brassicaceae, Caryophyllaceae and Juncaceae (Smith and Read, 1997).

Factors Influencing Amf Diversity

Diversity is summarised in various interactions between the organism and its environment in local communities or following dispersal to new sites (Morton *et al.,* 1995). According to Allen *et al.,* (1995), species richness, as well as spore density of AMF, depends upon the size of the area sampled, season and yearly variation in precipitation and temperature. Anthropogenic activities can be a factor in the loss of AM species diversity. The spore population dynamics depend on various biotic and abiotic factors such as host species, cropping patterns, crop rotation, crop management practices, use of fertilizers and pesticides, pH, temperature, nutrientlimitations, stress, etc.

Biotic Factors

- **Host:**

Any plant associating with a fungus can be designated as a 'host,' regardless of whether the association is beneficial or not (Brundrett, 2004). Molina *et al.,* (1992) suggested six specificity phenomena in mycorrhizal symbioses: (i) dependency versus independency (whether or not plants form mycorrhizae); (ii) facultative versus obligate symbionts (defines the ability or inability of symbionts to complete life cycles in the absence of mycorrhiza formation); (iii) fidelity to a class of mycorrhiza; (iv) host range of mycorrhizal fungi; (v) host receptivity (defines the numbers and diversity of mycorrhizal fungi accepted by a particular host); and (vi) ecological specificity (the influence of biotic and abiotic factors on the ability of plants to form functional mycorrhizae with particular fungi in natural soils. Mosse, (1956) first demonstrated the wide host range of AMF by producing mycorrhiza in apple, wheat, grasses, tomato and lettuce from surface-sterilized sporocarps associated with mycorrhizal strawberry roots. However, there are preferences in that the host plant species may select different mycorrhizal partners from the mix of fungi available in the soil. Among the agronomically important plant families, the Leguminosae and Gramineae are good hosts of AMF under normal growth conditions (Mehrotra and Baijal, 1992). They also found that in terms of colonization of fungal hyphae per unit length of root, plant species belonging to Leguminosae were superior, whereas in terms of the residual spore population of AMF species, plantspecies belonging to Gramineae were better. Intercropping of legumes with cereal crops promotes AMF proliferation more than the mono-cropping of either of them (Harinikumar *et al.,* 1990). Apparent host specificity may, however, occur if host susceptibility doesn't coincide with the propagule infectivity (Jasper *et al.*, 1987). However, it is important to distinguish between specificity, innate ability to colonize, ineffectiveness, amount of colonization and effectiveness. A host variety can switch from compatible to incompatible mycorrhizal association with a change in an environmental variable such as phosphorous level, soil water content, pH, salinity, temperature, intensity and quality of light.

Soil Organisms

The microbial population can either benefit or interfere with the establishment of AM associations (Vosátka and Gryndler, 1999; Gryndler, 2000). Phosphorus solubilizing microorganisms (PSM), which include species of *Pseudomonas*, *Bacillus*, *Flavobacterium*, *Arthrobacter* and *Aspergillus* have been found associated with AMF. These microorganisms can produce compounds that increase root cell permeability, thereby increasing the rates of root exudation and in turn, stimulate the growth of AMF hyphae in the root and rhizosphere (Jeffries *et al.*, 2003). The number of root exudates, which is lost from the living roots affects the microbial population. Physical factors, which can enhance root exudation, include the influence of low temperature, water stress and mechanical contact. Fracchia *et al.*, (2004) noted that *Aspergillus niger* and its exudates stimulated the germination and hyphal outgrowth of *Glomus mosseae* and *Gigaspora rosea* spores. Mycorrhizae influence soil microbial populations in the 'rhizosphere' and 'hyphosphere'. Rambelli, (1973), suggested the term 'mycorrhizosphere' as a substitute to 'rhizosphere', as there is a significant and dynamic microbial interaction in the mycorrhizal roots. The AMF network in the soil interacts with soil organisms competitively with pathogenic fungi, arthropods and nematodes. The presence of *Glomus mosseae* has been shown to affect the relative abundance of rhizosphere bacterial species (Ames *et al.*, 1984). On the other hand, AMF is used as food by grazing collembolans and burrowing earthworms (Fitter and Sanders, 1992). The seasonal breakdown of the AM fungal network provides the soil with carbon and nitrogen, which have a direct impact on the survival of the soil microflora and microfauna and subsequently on soil biodiversity. The ability of AMF to improve the soil structure by enhancing the stability of soil aggregates (Miller and Jastrow, 2000) through a glycoprotein, termed glomalin (Wright *et al.*, 1996), has a significant role in changing the dynamics of soil biodiversity.

Abiotic Factors

- **Seasons:**

Changes in spore population and percentage infection occurs commonly during the various growing seasons. Seasonal patterns in the formation of arbuscular mycorrhiza have been found to vary considerably (Lakshman *et al.*, 2006). Spore populations are typically at their lowest during the monsoon season (Singh and Varma 1981). Songachan and Kayang, (2012) studied the seasonal variation of AMF from the rhizosphere of *Flemingia vestita* plants in both cultivated and natural site of East Khasi hills, Meghalaya for two years and found out that the highest AMF spore population occurred during the winter season whereas, it was lowest during spring and summer seasons. Kumar, (2002) studied the spore population of AMF in soils from forest area at Alagar hills, Madurai, Tamil Nadu for a year and found that the highest AMF spore population occurred during winter season, whereas lowest was observed during rainy season. Khade and Rodrigues, (2004) studied the seasonal variation of AMF in the rhizosphere of *Musa acuminata* (cv. Savarbondi) in Goa and found that the species richness and spore densitywas maximum during pre-monsoon and minimum during post-monsoon season. New studies in the arid region of Rajasthan have shown that diversity of AMF varies with the rainfall patterns (Pande, 1999; Pande and Tarafdar, 2004). However, intra-specific variation among AMF species may also be present. Pringle and Bever, (2002), observed that *Acaulospora colossica* sporulated more frequently in the warm season, but *Gigaspora gigantea* sporulated more frequently in cool season. Gemma *et al.*, (1989) suggested that a combination of abiotic factors such as temperature and light and biotic factors such as the amount of photosynthates products, quality and quantity of root exudates and fluctuation of root hormone levels occurring during flowering and growth cessation are the primary non-genetic determinants of AMF sporulation. Diaz and Honrubia, (1994) however, suggested that an increase in spore production with the end of growing season might be related with root senescence, the presence of dead roots perhaps stimulated sporulation.

pH

It is known that soil factors such as pH restrict the distribution of some AMF species (Abbott and Robson, 1991). The occurrence of certain AMF species have been linked with soil factors: *Funneliformis mosseae* with fine-textured, fertile and high pH soils, *Acaulospora laevis* with coarse-textured soils and *Gigaspora* species with sand dune soil (Kendrick and Berch, 1985). Mohankumar *et al.*, (1988), surveyed the Madras coast (pH 7.8-8.1) between Ennore and Enjambakam for AM spores and found *Archaeospora schenckii*, *Claroideoglomusclaroideum, Rhizophagusclarus, Glomus intraradices, Glomus microcarpum, Glomus monosporum, Glomus occultum* and *Glomus pustulatum* associated with 35 plant species. *Glomus fasiculatum* has been found to be a common inhabitant of alkaline soil (pH 7.4-8.2) in the Coramandal coastal vegetation of India (Raman and Elumalai, 1991). *Glomus* *intraradices*is suitable for soils from about pH 6-9. Selvaraj *et al.,* (2001) observed that some *Glomus* species were very common in neutral to alkaline soil but not in acidic soils, while *Acaulospora* and *Scutellospora* species were found only in acidic soil.

Crop Management

Crop management practices affect the development and composition of AMF. Changes in soil conditions and cropping patterns may modify and change the dominance of AMF species. Changes in populations of Glomalean fungi have been observed when ecosystems are converted to monocultures or are severely disturbed, providing indirectevidence for habit preferences by these fungi. Forexample, a continuous monoculture of certain species may shift the AMF species composition of the community towards species, which may not be beneficial to the crop (Johnson *et al.,* 1992) and may even decrease the AMF spore population (Rao *et al.,* 1995). Fallowing in which land is left uncropped for one or more seasons is a common agricultural management practice in India. Singh *et al.,* (2003) found that Jhum (shifting cultivation) fallow land contained lower AMF population and less number of AMF species than the natural forest land. The decreased diversity of AMF in Jhum fallow land has been attributed to (i) repeated slash and burn agriculture in the past, which destroyed the AMF propagules, (ii) loss of host plants and (iii) unfavorable edaphic conditions for regeneration of AMF in fallow land. Crop rotation with non-mycotrophic plants, such as members of the Cruciferae has also been known to decreases the inoculum of AMF (Harinikumar and Bagyaraj, 1988). Fertilizers can promote the growth of microbial communities either by promoting growth directly by providing nutrients or indirectly by stimulating plant growth and enhancing flow of nutrients (Buyanovsky and Wagner, 1987). Growth of microbial communities may, however, also be limited by use of fertilizers because of soil acidification (Macrae *et al.,* 1999). Fertilizer application may also affect the composition of AMF species such that less efficient mycorrhizal species become dominant (Johnson, 1993). Douds and Schenck, (1990), found that a p-tolerantisolate of *Glomus intraradices* sporulated heavily when the N:P ratio of the host tissue was imbalanced towards P. In contrast, when N:P ratios of the host tissues were imbalanced towards N, *Gigaspora margarita* and *Acaulospora longula* sporulated heavily. Johnson, (1993) also noted that the relative abundance of *Glomus intraradices* increased in response to fertilization, while it decreased for *Gigaspora gigantea, Scutellospora calospora* and *Paraglomusoccultum.* In general, pesticides that enhance root exudation may increase mycorrhizal infection (Menge, 1982). Praveen Kumar & Bagyaraj, (1999) found that the pesticides Rilon (Thiophanate methyl) and Sumidin (Fenvalerate) increased the infection and sporulation of *Funneliformis mosseae* at half the recommended dose. Organic manures increase the biological activity in the soils and therefore, directly or indirectly influence the AMF activity. Hyphae of *Funneliformis mosseae*can grow saprophytically on organicmatter (Warner, 1984). Panja and Chaudhuri, (2006) noted that oilcake significantly suppressed the spore production in root associations, in spite of its very significant positive effect on total and mycorrhizal root biomass yield, but rice husk, which stimulated the root formation the least, showed the highest stimulation of spore production, both per unit soil volume and mycorrhizal root biomass. In a pot experiment, Tilak *et al.,* (2004) found that the mycorrhizal spore count and colonization of barley roots were more pronounced in soils amended with paddy straw compost than those amended with city compost. Tanu *et al.,* (2004) studied the effect of four organic amendments viz., leaf compost, vegetable compost, poultry manure and sewage sludge on the yield of herbage and essential oil of *Java citronella* (*Cymbopogon winterianus*) in the presence of native AMF and found that the highest number of AMF propagules were present in leaf compost amendedplots. Jamaluddin *et al.,* (2001) found *Glomusdeserticola*, *Glomus leptotichum*, *Glomus intraradices*, *Funneliformismosseae*, *Rhizophagusaggregatus* and *Rhizophagus invermaius* as the dominant species at the reclaimed sludge garden in Ballarpur, Maharastra.

Soil Disturbance

Soil disturbances affect the hyphal network resulting in delaysin AMF infectivity on plantroots and reduction in spore production. Tillage operations change the physical, chemical and biological properties of soil, thereby affecting the growth and distribution of roots. Kruckelmann, (1975) reported that strong disturbance due to rotary hoeing significantly reduced spore density. Propagules of mycorrhizal fungi may be absent from soils where severe soil disturbance has resulted in topsoil loss or where host plants are limited by adverse soil or site factors, such as salinity, aridity, water logging, or climatic extremes. Less severe forms of soil disturbance, including agricultural tillage (McGonigle and Miller, 1993), the rate and method of P application (Ryan *et al.,* 1994), fire and erosion can also influence the mycorrhizal fungus propagules and soildiversity. Hart and Reader, (2004) have noted that Gigasporineae isolates were significantly less affected than Glomineae isolates by soil disturbance in terms of root colonization, soilcolonization and spore densities.

Records of Amf from India

India is known for its wide variety of ecological zones and natural ecosystems. Descriptions of AMF were made in the early 1970s from the rhizosphere of plant species in different ecological zones of India. Thapar and Khan, (1973) reported 11 spore types from the rhizosphere of more than 25 tree species from forest soils in India and suggested that the occurrence of AMF spores is influenced by the subtending tree species, in addition to the land usage, soil moisture and texture. Bakshi, (1974) was among the pioneer workers, who reported 14 spore types viz., *Glomus macrocarpum, G. macrocarpum* var. *geospovum*, *Glomus mosseae*, *Glomus* sp., *Sclerocystis ceremoides*, *Sclerocystis* sp., *Gigaspora calospora*, *Acaulospora* sp., *Endogone gigantea*, *Endogone microcarpum* and three unidentified species of Endogone. Gerdemann and Bakshi, (1976) added two new species viz., *Glomus multicuale* and *Sclerocystis sinuosa* to the list of mycorrhizal fungi from India. The 1980s and 1990s witnessed a spurt in reports of AMF species from different regions of India. Bhattacharjee and Mukerji, (1980) reported several *Glomus* species from Indian soils. Bhattacharjee *et al.,* (1982) reported *Glomus reticulatum* from Bangalore. Gangopadhyay and Das, (1982) reported several AMF species from India. Mukherji *et al.,* (1983), reported *Glomus multisubstensum* from Delhi. Several species of AMF were reported from subtropical forests (Sharma *et al.,* 1987), forests and coastal regions of Andhra Pradesh (Manoharachary and Rao, 1991), Kodayar forest (Ganesan *et al.,* 1991), forests of Nilgiris (Raja *et at.,* 1991), Kodikkarai Reserve forests (Raghupathy and Mahadevan, 1991, 1992), Servarayans Hills in Tamil Nadu (Gopinathan *et al.,* 1991) and tropical forests (Bagyaraj *et al.,* 2002). The arid zone occupies about 12% of India's geographical area. The region is characterized by scanty and erratic rainfall, with high temperature, excessive evapotranspiration and massive erosion. Occurrence and distribution of AMF in semi-arid regions of India have been studied by several workers (Mukherji and Kapoor, 1986; Rachel *et al.,* 1989; Parthipon *et al.,* 1991; Neeraj and Varma, 1991; Mohan and Verma, 1995; Muthukumar and Udaiyan, 1991). AMF species have also been reported from the sand dunes of the west coast of India (Kulkarni *et al.,* 1997; Beena *et al.,* 2000) and Western Ghats of Goa (Rodrigues and Jaiswal, 2006). Beena *et al.,* (2000), have found that on the coastal dunes of the west coast of India, members of the family Glomaceae were dominant (61.3%), followed by Acaulosporaceae and Gigasporaceae (19.35%). In general, relatively low AMF species richness has been observed in semi-arid and arid regions of India. Gupta *et al.,* (2014) presented a survey of AMF species reported from different states of India and according to them *Funneliform mossae* (*Glomus mossae*) is the dominant mycorrhizal species, which is in contradiction with earlier reports which suggested *Glomus fasciculatum* and *Glomus macrocarpum* to be the most dominantly reported AMF species from India (Rani and Mukerji, 1990). Studies on AMF association indicate the uneven distribution of *Glomeromycota* amongstates, climatic zones and ecosystems in India and the tendency of the fungi with a wide geographical distribution to have a broad host range (Bansal *et al.,* 2012; Lakshmipathi *et al.,* 2012; Sharma and Yadav, 2013). Frequency of occurrence also varies at species level. *Funneliform mossae* has been found at almost all the sites investigated as sociating with a large variety of crop and wild plant species in both natural and disturbed soil. *Acaulospora laevis*, *Acaulospora spinosa*, *Rhizophagus aggregatus* etc. has also been reported from various states such as Karnataka, Goa, Tamil nadu, Jharkhand, Meghalaya, Kerala Andhra Pradesh, Rajasthan, Maharashtra, Bihar, Karnataka, Uttarakhand etc. According to Manoharachary *et al.,* (2005), 105 species of AMF have been reported from different states of India, but researchers have reported new AMF species subsequently. The present study gives an updated checklist of all the AMF species reported from different states of India, especially in the last few decades or so. Authors have tried their best to ensure that reports from every state of India have been included in the table given below. However, due to lack of publication from a few states, they have not been included in the list. Hopefully in near future research on the AMF diversity will be done on a large scale in these states, so, that we get an idea about the diversity and community composition of AMF species in the entire country. In this paper we have reported 153 AMF species reported from different states of India which is more than 105 AMF species reported by Manoharachary *et al.,* (2005) and 148 AMF species reported by Gupta *et al.,* (2014) but still well short of the estimated number of species known globally (about 270 species) developed on the basis of DNA sequence data from the epitypes (Schüßler and Walker, 2010; Öpik *et al.*, 2013; Oehl *et al.*, 2014). However, there remains scope for finding new AMF species from India because the study of AMF species in India has gained momentum only in the last 10-20 years and in some states of India the investigation of plants for the presence of AMF species is yet to be undertaken on a large scale. The studies on diversity and community compostion of AMF in India have been mostly confined to morphological aspects. The name of AMF species has also been updated in recent years based on the availability

Table 1: AMF species reported from different states of India.

S.No.	Species Name	Family	State	Reference
1	*Acaulosporaalpina*	Acaulosporaceae	Karnataka	Rajkumar *et al.*, 2012
2	*Acaulosporabireticulata*	Acaulosporaceae	Andhra Pradesh, Goa, Karnataka, Kerela, Maharastra, Sikkim, Tamil Nadu, Telangana	Deotare and Wankhede 2010, Baiju *et al.*, 2012, D'Souza and Rodrigues 2013, Bhutia 2013, Nagaraju and Manoharachary, 2017
3	*Acaulosporacapsiculata*	Acaulosporaceae	Meghalaya, Uttrakhand	Chaturvedi *et al.*, 2012, Songachan and Kayang, 2011a
4	*Acaulosporacavernata*	Acaulosporaceae	Meghalaya	Das and Kayang, 2010
5	*Acaulosporadelicata*	Acaulosporaceae	Goa, Karnataka, Meghalaya, Orissa	Singh and Jamaluddin 2011, Lakshmipathy *et al.*, 2012, Songachan and kayang 2011a
6	*Acaulosporadenticulata*	Acaulosporaceae	Andhra Pradesh, Karnataka, Kerala Maharashtra, Goa, Meghalaya,Orissa	Deotare and Wankhede 2010, Hindumathi and Reddy 2011, Singh and Jamaluddin 2011, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012, Songachan and Kayang 2011a
7	*Acaulosporadilatata*	Acaulosporaceae	Goa, Karnataka, Kerala, Meghalaya	Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011a
8	*Acaulosporaelegans*	Acaulosporaceae	Goa, Kerala, Tamil Nadu, Telangana	Nisha *et al.*, 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Hindumathi and Reddy 2011, Nagaraju and Manoharachary 2017
9	*Acaulosporafoveata*	Acaulosporaceae	Andhra Pradesh, Goa, Karnataka, Jammu & Kashmir, Telangana, Uttrakhand	Chaurasia *et al.*, 2005, Nirmalnath 2010, Shah *et al.*, 2010, Dessai and Rodrigues 2012, Renuka *et al.*, 2012, Nagaraju and Manoharachary 2017
10	*Acaulosporakoskei*	Acaulosporaceae	Meghalaya	Songachan and Kayang 2011a
11	*Acaulosporalacunosa*	Acaulosporaceae	Andhra Pradesh, Karnataka, Kerala, Meghalaya	Hindumathi and Reddy 2011, Baiju *et al.*, 2012, Songachan and Kayang 2011a
12	*Acaulosporalaevis*	Acaulosporaceae	AndhraPradesh, Bihar, Goa, Kerala, Jammu & Kashmir, Karnataka, Maharastra, Meghalaya, Tamil Nadu, Rajasthan, Uttrakhand	Charles *et al.*, 2008, Selwin *et al.*, 2009, Deotare and Wankhede 2010, Shah *et al.*, 2010, Chaturvedi *et al.*, 2012, Jahan *et al.*, 2012, Lakshmipathy *et al.*, 2012, D'Souza and Rodrigues 2013, Songachan and Kayang 2011a, Prasad *et al.*, 2011,
13	*Acaulosporalongula*	Acaulosporaceae	Karnataka, Kerala, Uttarakhand	Nirmalnath 2010, Baiju *et al.*, 2012, Chaturvedi *et al.*, 2012

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14	*Acaulosporamorrowiae*	Acaulosporaceae	Andhra Pradesh, Goa, Karnataka, Kerela, Meghalaya, Rajasthan	Hindumathi and Reddy 2011, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Vyas and Vyas 2012, Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011a
15	*Acaulosporamellea*	Acaulosporaceae	Andhra Pradesh, Assam, Goa, Karnataka, Madhya Pradesh, Uttarakhand, Meghalaya, Kerala	Hindumathi and Reddy 2011, Baiju *et al.*, 2012, Jha *et al.*, 2017 Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012, Sharmah and Jha 2014, Songachan and Kayang 2011a,
16	*Acaulosporamyriocarpa*	Acaulosporaceae	Goa, Karnataka, Kerala	Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012
17	*Acaulosporapaulinae*	Acaulosporaceae	Jammu & Kashmir, Uttarakhand	Shah *et al.*, 2010, Chaturvedi *et al.*, 2012
18	*Acaulosporarehmii*	Acaulosporaceae	Goa, Karnatka, Kerela, Maharastra, Meghalaya	Das and Kayang 2010, Deotare and Wankhede 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012
19	*Acaulospora rugosa*	Acaulosporaceae	Goa	Dessai and Rodrigues 2012
20	*Acaulosporascrobiculata*	Acaulosporaceae	Andhra Pradesh, Karnataka, Kerela, Madhya Pradesh, Maharastra, Orissa, Meghalaya, Goa, Uttarakhand, West Bengal, TamilNadu	Gupta *et al.*, 2009, Deotare and Wankhede 2010, Nisha *et al.*, 2010, Hindumathi and Reddy 2011, Singh and Jamaluddin 2011, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011a, Baiju *et al.*, 2012,
21	*Acaulosporasoloidea*	Acaulosporaceae	Karnataka	Rajkumar *et al.*, 2012
22	*Acaulospora spinosa*	Acaulosporaceae	Andhra Pradesh, Assam, Goa, Jammu & Kashmir, Karnataka, West Bengal, Madhya Pradesh, Maharastra, Meghalaya, Sikkim, TamilNadu, Telangana, Uttarakhand Manipur, Kerela	Gupta *et al.*, 2009, Selwin *et al.*, 2009, Shah *et al.*, 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Sarwade *et al.*, 2011,Bhutia 2013, Sharmah and Jha 2014, Songachan and Kayang 2011a, Surendirakumar *et al.*, 2016, Nagaraju and Manoharachary 2017
23	*Acaulosporasplendida*	Acaulosporacea	Goa	Khade 2011
24	*Acaulosporasporocarpia*	Acaulosporaceae	Rajasthan	Vyas and Vyas 2012
25	*Acaulosporathomii*	Acaulosporaceae	Kerela, Maharastra	Bindu and Harikumar 2008, Sarwade *et al.*, 2011

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26	*Acaulosporatuberculata*	Acaulosporaceae	Bihar, Goa, Karnataka, Kerela, Meghalaya, Rajasthan	Prasad 2005, Baiju *et al.*, 2012, Das and Kayang 2010, Prasad *et al.*, 2011, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012, Songachan and Kayang 2011a
27	*Ambispora appendicula* (Syn. *Acaulosporaappendicula*)	Ambisporaceae	Andhra Pradesh, Goa, Karnataka, Kerela, Maharastra	Baiju *et al.*, 2012, Renuka *et al.*, 2012; Dessai and Rodrigues 2012, Pawaar and Kakde 2012, Lakshmipathy *et al.*, 2012,
28	*Ambisporacallosa* (Syn.*Glomuscallosum*)	Ambisporaceae	Maharastra	Deotare and Wankhede 2010
29	*Ambisporafecundispora* (Syn.*Glomusfecundispora*)	Ambisporaceae	Maharastra	Deotare and Wankhede 2010
30	*Ambisporagerdemannii* (Syn. *Glomusgerdemanii*)	Ambisporaceae	Karnataka, Uttrakhand	Chaturvedi *et al.*, 2012, Lakshmipathy *et al.*, 2012
31	*Ambisporaleptoticha* (Syn. *Glomus leptotichum*)	Ambisporaceae	Karnataka, Maharastra	Deotare and Wankhede 2010, Lakshmipathy *et al.*, 2012
32	*Ambisporanicolsonii* (Syn. *Acaulosporanicolsonii*)	Ambisporaceae	Andhra Pradesh, Karnataka, Goa, MadhyaPradesh, Telangana, West Bengal	Nirmalnath 2010, Dessai and Rodrigues 2012, Jahan *et al.*, 2012, Nagaraju and Manoharachary 2017
33	*Archaeosporaschenckii* (Syn. *Entrophosporaschenckii*)	Archaeosporaceae	Karnataka	Lakshmipathy *et al.*, 2012
34	*Archaeosporatrappei* (Syn. *Acaulosporatrappe*)	Archaeosporaceae	Jammu & Kashmir, Karnataka, Tamil Nadu	Selwin *et al.*, 2009; Shah *et al.*, 2010, Lakshmipathy *et al.*, 2012
35	*Archaeosporaundulata* (Syn.*Acaulosporaundulata*)	Archaeosporaceae	Goa, Karnataka	Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012
36	*Cetraspora pellucida* (Syn.*Gigasporapellucida*)	Gigasporaceae	Jammu & Kashmir, Maharastra, Meghalaya, Uttrakhand	Shah *et al.*, 2010, Chaturvedi *et al.*, 2012, Pawaar and Kakde 2012, Songachan and Kayang 2011b
37	*Claroideoglomusclaroideum* (Syn. *Glomus claroideum*)	Claroideoglomeraceae	Assam, Goa, Arunachal Pradesh, Jammu & Kashmir, Madhya Pradesh, Kerela, Meghalaya, Uttrakhand, Maharastra	Khade and Adholeya 2008, Deotare and Wankhede 2010, Shah *et al.*, 2010, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Sharmah and Jha2014, Songachan and Kayang 2011a, Bordoloi *et al.*, 2015, Baiju *et al.*, 2012,
38	*Claroideoglomusdrummondii* (Syn. *Glomus drummondii*)	Claroideoglomeraceae	Sikkim	Bhutia 2013
39	*Claroideoglomus luteum* (Syn. *Glomus luteum*)	Claroideoglomeraceae	Jammu & Kashmir, Karnataka, Meghalaya	Shah *et al.*, 2010, Rajkumar *et al.*, 2012, Songachan and Kayang 2011a

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40	*Claroideoglomusetunicatum* (Syn. *Glomus etunicatum*)	Claroideoglomeraceae	AndhraPradesh, Arunachal Pradesh, Goa,Gujarat, Jammu & Kashmir, Karnataka, Madhya Pradesh, Maharastra, Meghalaya, Tamil Nadu, Uttrakhand	Deotare and Wankhede 2010, Shah *et al.*, 2010, Hindumathi and Reddy 2011, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Priyadharsini *et al.*, 2012, Arya *et al.*, 2013, Jha *et al.*, 2017, Songachan and Kayang 2011a, Bordoloi *et al.*, 2015
41	*Claroideoglomuslamellosum* (Syn. *Glomus lamellosum*)	Claroideoglomeraceae	Jammu & Kashmir	Shah *et al.*, 2010
42	*Corymbiglomusglobiferum* (Syn. *Glomus globiferum*)	Diversisporaceaea	Andhra Pradesh, Goa, Karnataka	Rani *et al.*, 2004, Khade and Rodrigues 2008, Lakshmipathy *et al.*, 2012
43	*Corymbiglomustortuosum* (Syn. *Glomus tortuosum*)	Diversisporaceaea	Karnataka, Maharastra, Meghalaya	Das and Kayang 2010, Pawaar and Kakde 2012, Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011b
44	*Dentiscutatacerradensis* (Syn. *Scutellosporacerradensis*)	Gigasporaceae	Karnataka, Meghalaya	Rajkumar *et al.*, 2012, Songachan and Kayang 2011a
45	*Dentiscutataheterogama* (Syn.*Endogoneheterogama*)	Gigasporaceae	Jammu & Kashmir, Karnataka, Maharastra, Meghalaya	Deotare and Wankhede 2010, Shah *et al.*, 2010, Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011b
46	*Dentiscutatanigerita*	Gigasporaceae	Goa, Karnataka	Khade 2011, Rajkumar *et al.*, 2012
47	*Dentiscutatareticulata* (Syn.*Gigasporareticulata*)	Gigasporaceae	Andhra Pradesh, Goa	Khade 2011, Renuka *et al.*, 2012
48	*Diversisporaaurantia* (Syn. *Glomus aurantium*)	Diversisporaceae	Arunachal Pradesh	Bordoloi *et al.*, 2015
49	*Diversisporaepigaea* (Syn. *Glomus epigaeum*)	Diversisporaceae	Andhra Pradesh	Hindumathi and Reddy 2011
50	*Diversisporaversiformis*	Diversisporaceae	Karnataka, Meghalaya	Lakshmipathy *et al.*, 2012, Songachan and Kayang 2011b
51	*Dominikaminuta* (Syn. *Glomus minutum*)	Glomeraceae	Meghalaya	Songachan and Kayang 2011a
52	*Entrophosporainfrequens* (Syn.*Glomusinfrequens*)	Entrophosporaceae	Jammu & Kashmir, Telangana, Uttrakhand	Gupta *et al.*, 2009, Shah *et al.*,2010, Renuka *et al.*, 2012, Nagaraju and Manoharachary, 2017
53	*Funneliformiscaledonius* (Syn. *Endogonemacrocarpavar. caledonia*)	Glomeraceae	Andhra Pradesh, Jammu & Kashmir, Karnataka, Goa, Meghalaya, Telangana	Shah *et al.*, 2010; Dessai and Rodrigues2012, Lakshmipathy *et al.*, 2012, Nagaraju and Manoharachary, 2017, Songachan and Kayang 2011a, Renuka *et al.*, 2012,
54	*Funneliformisdimorphicus* (Syn.*Glomusdimorphicum*)	Glomeraceae	Jammu & Kashmir, Karanataka, Maharastra, West Bengal	Deotare and Wankhede 2010, Nirmalnath 2010

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55	*Funneliformiscoronatus* (Syn. *Glomus coronatum*)	Glomeraceae	Arunachal Pradesh, Karnataka	Rajkumar *et al.*, 2012, Bordoloi *et al.*, 2015
56	*Funneliformisfragilistratus* (Syn. *Glomus fragilistratum*)	Glomeraceae	Kerela, Maharastra	Bindu and Harikumar 2004, Deotare and Wankhede 2010
57	*Funneliformisgeosporus* (Syn.*Endogonemacrocarpa*)	Glomeraceae	Andhra Pradesh, Goa, Karnataka, Maharastra, Manipur, Meghalaya, TamilNadu Kerela	Rani *et al.*, 2004, Nisha *et al.*, 2010, Dessai and Rodrigues2012, Lakshmipathy *et al.*, 2012, Sarwade *et al.*, 2011, Songachan and Kayang 2011a, Surendrakumar *et al.*, 2016 Charles *et al.*, 2008,
58	*Funneliformismonosporus* (Syn.*Glomusmonosporum*)	Glomeraceae	Goa, Karnataka	Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012
59	*Funneliformismosseae* (Syn. *Glomus mossae*, *Endogonemossae*)	Glomeraceae	Andhra Pradesh, Arunachal Pradesh, Bihar,Goa, Jammu & Kashmir, Karnataka, Kerela, Madhya Pradesh, Maharastra, Meghalaya, Orissa, Rajasthan, TamilNadu, Tripura, Uttrakhand, West Bengal	Prasad 2005, Deotare and Wankhede2010, Sudha and Ammani 2010, Nisha *et al.*, 2010, Shah *et al.*,2010, Hindumathi and Reddy 2011, Singh and Jamaluddin 2011, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Vyas and Vyas 2012, Songachan and Kayang 2011a, Bordoloi *et al.*, 2015
60	*Funneliformishalonatus* (Syn. *Glomus halonatum*)	Glomeraceae	Karnataka	Lakshmipathy *et al.*, 2012
61	*Funneliformisverruculosum* (Syn. *Glomus verruculosum*)	Glomeraceae	Karnataka, Meghalaya	Rajkumar *et al.*, 2012, Songachan and Kayang 2011a
62	*Geosiphonpyriformis* (Syn.*Botrydiumpyriforme*)	Geosiphonaceae	Maharastra	Deotare and Wankhede 2010
63	*Gigasporaalbida*	Gigasporaceae	Andhra Pradesh, Karnataka, Kerela, Maharastra, Goa, West Bengal	Deotare and Wankhede 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012
64	*Gigasporacandida* (Syn. *Gigasporaalboaurantiaca*)	Gigasporaceae	Andhra Pradesh, Gujarat	Renuka *et al.*, 2012, Arya *et al.*, 2013
65	*Gigasporadecipiens*	Gigasporaceae	Andhra Pradesh, Goa, Jharkhand, Kerela, Rajasthan	Shah *et al.*, 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Renuka *et al.*, 2012, Sharma and Yadav 2013
66	*Gigasporagigantean* (Syn.*Endogone gigantea*)	Gigasporaceae	Andhra Pradesh, Goa, Kerela, Maharastra, Orissa, Rajasthan,Sikkim, Uttrakhand	Hindumathi and Reddy 2011, Singh and Jamaluddin 2011, Baiju *et al.*, 2012, Bhutia 2013, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Kamble *et al.*, 2012 b, Tamboli and Vyas 2012

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67	*Gigaspora margarita*	Gigasporaceae	Andhra Pradesh, Jammu & Kashmir, Karnatka, Meghalaya, Orissa, Rajasthan, Uttarkhand, West Bengal	Gupta *et al.*, 2009, Das and Kayang 2010, Shah *et al.*, 2010, Ghosh and Verma 2011, Singh and Jamaluddin 2011, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Tamboli and Vyas 2012
68	*Gigasporaramisporophora*	Gigasporaceae	Goa, Gujarat	Dessai and Rodrigues 2012, Arya *et al.*, 2013
69	*Gigasporarosea*	Gigasporaceae	Andhra Pradesh, Karnataka, Kerela, Maharastra, Orissa, Rajasthan, Telangana	Rani *et al.*, 2004, Charles *et al.*, 2008, Singh and Jamaluddin 2011, Kamble *et al.*, 2012b, Lakshmipathy *et al.*, 2012, Vyas and Vyas 2012, Nagaraju and Manoharachary, 2017
70	*Glomus ambisporum*	Glomeraceae	Andhra Pradesh, Goa, Karnataka, Kerela, Maharastra, Manipur, TamilNadu, Uttrakhand, West Bengal	Chaurasia *et al.*, 2005, Selwin *et al.*, 2009, Baiju *et al.*, 2012, Surendirakumar*et al.*, 2016, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012, Renuka *et al.*, 2012, Sarwade *et al.*, 2011
71	*Glomus arborense*	Glomeraceae	Madhya Pradesh, Orrissa	Singh and Jamaluddin 2011, Jha *et al.*, 2017
72	*Glomus austral* (Syn. *Endogoneaustralis*)	Glomeraceae	Karnataka, Kerela, Maharastra	Bindu and Harikumar 2008, Lakshmipathy *et al.*, 2012, Sarwade *et al.*, 2011
73	*Glomus boreale* (Syn.*Endogoneborealis*)	Glomeraceae	Goa, Karnataka, Maharastra	Khade 2011, Pawaar and Kakde 2012, Lakshmipathy *et al.*, 2012
74	*Glomus botryoides*	Glomeraceae	Kerela, Maharastra, Telangana	Deotare and Wankhede 2010, Baiju *et al.*, 2012, Nagaraju and Manoharachary 2017
75	*Glomus canadense* (Syn.*Endogone canadensis*)	Glomeraceae	Karnataka, Kerela	Baiju *et al.*, 2012, Lakshmipathy *et al.*, 2012
76	*Glomus cerebriforme*	Glomeraceae	Madhya Pradesh	Jha *et al.*, 2017
77	*Glomus citricola*	Glomeraceae	Gujarat, Karnataka, Madhya pradesh	Baiju *et al.*, 2012, Lakshmipathy *et al.*, 2012, Arya *et al.*, 2013,
78	*Glomus clavispora*	Glomeraceae	Goa,Karnataka, Meghalaya, Tripura	Khade 2011, Lakshmipathy *et al.*, 2012, Rajkumar *et al.*, 2012, Renuka *et al.*, 2012, Debnath *et al.*, 2014, Songachan and Kayang 2011a
79	*Glomus convolutum*	Glomeraceae	Andhra Pradesh	Renuka *et al.*, 2012
80	*Glomus delhiense*	Glomeraceae	Karnataka	Lakshmipathy *et al.*, 2012

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81	*Glomus deserticola*	Glomeraceae	Andhra Pradesh, Karnataka, Kerela, Orissa, Rajasthan	Bindu and Harikumar 2004, Singh and Jamaluddin 2011, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Tamboli and Vyas 2012
82	*Glomus fasiculatum* (Syn.*Endogonefasiculata*)	Glomeraceae	Arunachal Pradesh, Gujarat	Arya *et al.*, 2013, Bordoloi *et al.*, 2015
83	*Glomus fistulosum*	Glomeraceae	Andhra Pradesh	Jahan *et al.*, 2012
84	*Glomus flavisporum* (Syn.*Endogoneflavispora*)	Glomeraceae	Goa, Karnataka	Dessai and Rodrigues 2012, Kamble *et al.*, 2012 a, b
85	*Glomus formosanum*	Glomeraceae	Goa, Maharastra	Deotare and Wankhede 1981, Dessai and Rodrigues 2012
86	*Glomus fuegianum* (Syn.*Endogonefuegiana*)	Glomeraceae	Gujarat, Meghalaya	Das and Kayang 2010, Arya *et al.*, 2013
87	*Glomus glomerulatum*	Glomeraceae	Goa, Gujarat	Dessai and Rodrigues 2012, Arya *et al.*, 2013
88	*Glomus goaensis*	Glomeraceae	Goa, Maharastra	Kamble *et al.*, 2012b
89	*Glomus geosporum*	Glomeraceae	Arunachal Pradesh, Gujarat	Bordoloi *et al.*, 2015
90	*Glomus halan*	Glomeraceae	Maharastra	Sarwade *et al.*, 2011
91	*Glomus heterosporum*	Glomeraceae	Goa, Karnataka, Maharastra	Deotare and Wankhede 1981, Khade and Rodrigues 2008, Lakshmipathy *et al.*, 2012
92	*Glomus hoi*	Glomeraceae	Goa, Gujarat, Karnataka, Madhya Pradesh	Vyas *et al.*, 2007, Arya *et al.*, 2013, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012
93	*Glomus hyderabadensis*	Glomeraceae	Andhra Pradesh	Rani *et al.*, 2004
94	*Glomus macrocarpum*	Glomeraceae	Andhra Pradesh, Goa, Gujarat, Karnataka, Maharastra, Meghalaya, Tamil Nadu, Telangana, Tripura, Uttrakhand	Das and Kayang 2010, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Nisha *et al.*, 2010, Arya *et al.*, 2013, Renuka *et al.*, 2012, Sarwade *et al.*, 2011, Debnath *et al.*, 2014, Nagaraju and Manoharachary, 2017
95	*Glomus magnicaule*	Glomeraceae	Karnataka, Madhya Pradesh, WestBengal	Lakshmipathy *et al.*, 2012,
96	*Glomus melanosporum*	Glomeraceae	Maharastra	Deotare and Wankhede 2010
97	*Glomus microcarpum* (Syn. *Endogonemicrocarpus*)	Glomeraceae	Andhra Pradesh, Arunachal Pradesh, Goa, Karnataka, Kerela, Maharashtra, Meghalaya, Rajasthan, Tamil Nadu	Charles *et al.*, 2008, Deotare and Wankhede 2010, Nisha *et al.*, 2010, Hindumathi and Reddy 2011, Prasad *et al.*, 2011, Dessai and Rodrigues 2012, Kamble *et al.*, 2012 a, b, Renuka *et al.*, 2012, Songachan and Kayang 2011a, Bordoloi *et al.*, 2015

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98	*Glomus multicaule*	Glomeraceae	Goa, Karnataka, Maharastra, Meghalaya, Tripura	Das and Kayang 2010, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Sarwade *et al.*, 2011, Debnath *et al.*, 2014
99	*Glomus multisubstensum*	Glomeraceae	Andhra Pradesh, Karnataka, Maharastra	Deotare and Wankhede 2010, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012
100	*Glomus nanolumen*	Glomeraceae	Goa	D'Souza and Rodrigues 2013
101	*Glomus pachycaulis*	Glomeraceae	Goa, Karnataka, Maharastra, Uttrakhand	Khade 2008, Chaturvedi *et al.*, 2012, Lakshmipathy *et al.*, 2012, Kamble *et al.*, 2012b
102	*Glomus pansihalos*	Glomeraceae	Karnataka, Kerela, Maharastra	Deotare and Wankhede 2010, Baiju *et al.*, 2012, Lakshmipathy *et al.*, 2012
103	*Glomus perpusillum*	Glomeraceae	Karnataka,	Rajkumar *et al.*, 2012
104	*Glomuspustulatum*	Glomeraceae	Andhra Pradesh, Karnataka, Kerela, Madhya Pradesh, Maharastra, West Bengal Uttrakhand	Rani *et al.*, 2004, Chaurasia *et al.*, 2005, Deotare and Wankhede 2010, Baiju *et al.*, 2012, Lakshmipathy *et al.*, 2012
105	*Glomus radiatum* (Syn.*Endogone radiate*)	Glomeraceae	Karnataka, Kerela, Maharastra	Baiju *et al.*, 2012, Lakshmipathy *et al.*, 2012, Pawaar and Kakde 2012
106	*Glomus reticulatum*	Glomeraceae	Andhra Pradesh, Karnataka, Maharastra, Tamil Nadu, Kerela	Charles *et al.*, 2008, Deotare and Wankhede 2010, Nisha *et al.*, 2010, Hindumathi and Reddy 2011, Lakshmipathy *et al.*, 2012
107	*Glomus segmentatum*	Glomeraceae	Karnataka, Kerela, Maharastra	Baiju *et al.*, 2012, Pawaar and Kakde 2012, Lakshmipathy *et al.*, 2012
108	*Glomus sinuosum*	Glomeraceae	Tamil Nadu	Priyadharsini *et al.*, 2012
109	*Glomus spinosum*	Glomeraceae	Meghalaya	Songachan and Kayang 2011a
110	*Glomus tenebrosum* (Syn.*Endogonetenebrosa*)	Glomeraceae	Meghalaya	Songachan and Kayang 2011a
111	*Glomus versiforme* (Syn.*Endogoneversiformis*)	Glomeraceae	Karnataka, Manipur, Meghalaya, Sikkim	Lakshmipathy *et al.*, 2012, Bhutia 2013, Songachan and Kayang 2011b, Surendirakumar *et al.*, 2016
112	*Oehliadiaphana* (Syn. *Glomus diaphanum*)	Glomeraceae	Jammu & Kashmir	Shah *et al.*, 2010, Jha *et al.*, 2017 Lakshmipathy *et al.*, 2012
113	*Pacisporachimonobambuse* (Syn. *Glomuschimonobambusae*)	Pacisporaceae	Karnataka, Meghalaya	Das and Kayang 2010, Rajkumar *et al.*, 2012
114	*Pacisporarobigina*	Pacisporaceae	Meghalaya	Songachan and Kayang 2011a
115	*Pacisporascintillans* (Syn. *Glomus scintillans*)	Pacisporaceae	Karnataka,Kerela	Lakshmipathy *et al.*, 2012

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116	*Paraglomusalbidum* (Syn. *Glomus albidum*)	Paraglomeraceae	Arunachal Pradesh, Goa, Karnataka, Kerela,Maharastra	Deotare and Wankhede 2010, Baiju *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Bordoloi *et al.*, 2015
117	*Paraglomusbolivianum* (Syn.*Pacisporaboliviana*)	Paraglomeraceae	Meghalaya	Das and Kayang 2010
118	*Paraglomuslaccatum* (Syn.*Glomuslaccatum*)	Paraglomeraceae	Uttrakhand	Chaturvedi *et al.*, 2012
119	*Paraglomuslacteum* (Syn. *Glomus lacteum*)	Paraglomeraceae	Karnataka, Maharashtra	Deotare and Wankhede 2010, Lakshmipathy *et al.*, 2012
120	*Paraglomusoccultum* (Syn. *Glomus occultum*)	Paraglomeraceae	Arunachal Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu, West Bengal	Selwin *et al.*, 2009, Rajkumar *et al.*, 2012, Bordoloi *et al.*, 2015
121	*Racocetracoralloidea* (Syn.*Gigasporacoralloidea*)	Gigasporaceae	Meghalaya	Songachan and Kayang 2011a
122	*Racocetrafulgida* (Syn.*Scutellosporafulgida*)	Gigasporaceae	Meghalaya	Songachan and Kayang 2011a
123	*Racocetragregaria* (Syn.*Gigasporagregaria*)	Gigasporaceae	Andhra Pradesh, Goa, Rajasthan, Tamil Nadu	Nisha *et al.*, 2010, Dessai and Rodrigues 2012, Renuka *et al.*, 2012, Sharma and Yadav 2013
124	*Racocetrapersica* (Syn.*Gigasporapersica*)	Gigasporaceae	Kerela, Orissa, Uttrakhand	Bindu and Harikumar 2004, Singh and Jamaluddin 2011, Chaturvedi *et al.*, 2012
125	*Racocetraverrucosa* (Syn.*Gigaspora verrucose*)	Gigasporaceae	Andhra Pradesh, Jharkhand, Karnataka	Shah *et al.*, 2010, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012
126	*Racocetraweresubiae* (Syn. *Scutellosporaweresubaie*)	Gigasporaceae	Andhra Pradesh	Renuka *et al.*, 2012
127	*Redeckerafulva* (Syn.*Paurocotylisfulvum*)	Diversisporaeae	Karnataka	Lakshmipathy *et al.*, 2012
128	*Redeckerapulvinata* (Syn. *Endogone pulvinate*)	Glomeraceae	Kerela	Baiju *et al.*, 2012
129	*Rhizoglomusmicroaggregatum* (Syn. *Glomus microaggregatum*)	Glomeraceae	Kerela, Meghalaya, Sikkim	Bindu and Harikumar 2004, Das and Kayang 2010, Bhutia 2013, Songachan and Kayang 2011a
130	*Rhizophagusaggregatus* (Syn.*Glomusaggregatum*)	Glomeraceae	Andhra Pradesh, Bihar,Goa, Karnataka Madhya Pradesh, Maharashtra Manipur, Meghalaya, Rajasthan, TamilNadu, Kerela Uttrakhand, WestBengal	Chaurasia *et al.*, 2005, Prasad 2005, Baiju *et al.*,2012, Das and Kayang 2010, Nisha *et al.*, 2010, Ghosh and Verma 2011, Jha *et al.*, 2011, Arya *et al.*, 2013, Prasad *et al.*, 2011, D'Souza and Rodrigues 2013, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Sureindrakumar *et al.*, 2016

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131	*Rhizophagusfasciculatus* (Syn.*Endogone fasciculate*)	Glomeraceae	Andhra Pradesh, Goa, Karnataka, Kerela, Madhya Pradesh, Maharastra, Manipur, Orissa, Rajasthan, Tamil Nadu, Telangana, Uttrakhand	Bindu and Harikumar 2004, Prasad 2005, Nirmalnath 2010, Chaurasia *et al.*, 2005, Shah *et al.*, 2010, Nisha *et al.*,2010, Singh and Jamaluddin 2011, Renuka *et al.*, 2012, Sarwade *et al.*, 2012, D'Souza and Rodrigues 2013, Sharma and Yadav 2013, Jha *et al.*,2017, Nagaraju and Manoharachary, 2017
132	*Rhizophagusintraradices* (Syn. *Glomus intraradices*)	Glomeraceae	Andhra Pradesh, Bihar, Goa, Jammu & Kashmir, Karnataka, Madhya Pradesh, Maharastra, Meghalaya, Orissa,Rajasthan, Uttrakhand	Prasad *et al.*, 1990, Prasad 2005, Jha *et al.*, 2017, Shah *et al.*, 2010, Singh and Jamaluddin 2011, Chaturvedi *et al.*, 2012, Rajkumar *et al.*, 2012, Renuka *et al.*, 2012, Sarwade *et al.*, 2012, D'Souza and Rodrigues 2013, Songachan and Kayang 2011a
133	*Rhizophagusinvermaius* (Syn. *Glomus invermaium*)	Glomeraceae	Andhra pradesh, Karnataka, Madhya Pradesh	Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Jha *et al.*, 2017
134	*Rhizophagusmanihotis* (Syn. *Glomus manihotis*)	Glomeraceae	Assam, Goa, Karnataka, Maharashtra	Deotare and Wankhede 2010, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012, Sharmah and Jha 2014
135	*Sclerocystiscoremioides* (Syn. *Glomus coremioides*)	Glomeraceae	Andhra Pradesh, Goa	Dessai and Rodrigues 2012, Renuka *et al.*, 2012
136	*Sclerocystisdussi*	Glomeraceae	Tamil Nadu	Selwin *et al.*, 2009
137	*Sclerocystisrubiformis*	Glomeraceae	Andhra Pradesh, Goa, Karnataka, Meghalaya, Uttrakhand	Chaurasia *et al.*, 2005, Charles *et al.*, 2008, Hindumathi and Reddy 2011, Dessai and Rodrigues 2012, Jahan *et al.*, 2012, Rajkumar *et al.*, 2012, Renuka *et al.*, 2012, Songachan and Kayang 2011a
138.	*Sclerocystissinuosa*	Glomeraceae	Andhra Pradesh, Arunachal Pradesh, Goa,Karnataka, Maharastra, Meghalaya, Uttrakhand	Chaurasia *et al.*, 2005, Khade 2011, Jahan*et al.*, 2012, Rajkumar *et al.*, 2012, Renuka *et al.*, 2012, Sarwade *et al.*, 2012, Songachan and Kayang 2011a, Bordoloi *et al.*, 2015
139	*Sclerocystistaiwanensis*	Glomeraceae	Goa, Karnataka, Uttrakhand	Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Rajkumar *et al.*, 2012

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140	*Scutellosporaarenicola*	Gigasporaceae	Maharastra, Telangana	Pawaar and Kakde 2012, Nagaraju and Manoharachary, 2017
141	*Scutellosporaauriglobа* (Syn.*Gigasporaauriglobа*)	Gigasporaceae	Kerela, Maharastra	Charles *et al.*, 2008, Pawaar and Kakde 2012
142	*Scutellosporabiornata*	Gigasporaceae	Goa	Dessai and Rodrigues 2012
143	*Scutellosporaalospora* (Syn.*Endogonecalospora*)	Gigasporaceae	Andhra pradesh, Goa, Jammu & Kashmir, Karnataka, Kerela, Meghalaya, Rajasthan, Uttrakhand	Charles *et al.*, 2008, Shah *et al.*,2010, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Renuka *et al.*, 2012, Tamboli and Vyas 2012, Songachan and Kayang 2011b
144	*Scutellosporadipurpurescens*	Gigasporaceae	Jammu & Kashmir	Shah *et al.*, 2010
145	*Scutellosporaerythropus* (Syn.*Gigasporaerythropus*)	Gigasporaceae	Andhra Pradesh, Jammu & Kashmir, Meghalaya	Shah *et al.*, 2010, Renuka *et al.*, 2012, Songachan and Kayang 2011a
146	*Scutellosporaheterogama* (Syn.*Endogoneheterogama*)	Gigasporaceae	Arunachal Pradesh	Bordoloi *et al.*, 2015
147	*Scutellosporaminuta* (Syn.*Gigasporaminuta*)	Gigasporaceae	Maharastra, Telangana	Deotare and Wankhede 2010, Nagaraju and Manoharachary 2017
148	*Scutellosporanigra* (Syn.*Gigasporanigra*)	Gigasporaceae	Andhra Pradesh, Goa, Karnataka, Rajasthan	Prasad *et al.*, 1990, Shobha and Chandrashekar 2007, Hindumathi and Reddy 2011, Dessai and Rodrigues 2012, Renuka *et al.*, 2012
149	*Scutellosporapernambucana*	Gigasporaceae	Meghalaya	Songachan and Kayang 2011a
150	*Scutellospora rubra*	Gigasporaceae	Meghalaya, Sikkim	Bhutia 2013, Songachan and Kayang 2011a
151	*Septoglomusconstrictum* (Syn. *Glomus constrictum*)	Glomeraceae	Andhra Pradesh, Bihar, Goa, Karnataka, Kerela, Meghalaya, Rajasthan, Uttrakhand	Prasad 2005, Renuka *et al.*, 2012, Das and Kayang 2010, Baiju *et al.*, 2012, Chaturvedi *et al.*, 2012, Dessai and Rodrigues 2012, Lakshmipathy *et al.*, 2012, Vyas and Vyas 2012
152	*Septoglomusviscosum* (Syn. *Glomus viscosum*)	Glomeraceae	Meghalaya, Tamil Nadu	Songachan and Kayang 2011a
153	*Septoglomusxanthium* (Syn.*Glomusxanthium*)	Glomeraceae	Arunachal Pradesh	Bordoloi *et al.*, 2015

of type specimens and molecular sequence data (Manoharachary *et al.*, 2005; Oehl *et al.*, 2008, 2011; Schüßler and Walker, 2010; Goto *et al.*, 2012; Redecker *et al.*, 2013). Table 1 represents the total number of AMF species isolated an identified from different parts of India.

Amf Germplasm Collection

The development of germplasm collections of AMF in India have really escalated in recent years but India is yet to have a full-fledged germplasm bank dedicated to Glomeromycota. Collection of AMF germplasm in India is maintained by different AMF research groups, for example, The CMCC (Centre for Mycorrhizal Culture Collection) which was started in the year 1993 with seed support from Department of Biotechnology, Government of India. Indian Arbuscular Mycorrhizal database is another such research group maintained by Delhi University. Indian Glomeromycota is yet to be well represented in the international databases of AMF such as GBIF (Global Biodiversity Information Facility) and Maarj AM, the mycorrhizal distribution database (Yang *et al.*, 2012; Öpik *et al.*, 2013).

Future Challenges

Research on AMF has mostly revolved around identification of AMF associations in different plant communities and their distribution patterns across different habitats in India. However, this goal remains a distant one and the mycorrhizal status and pattern of fungal diversity in some plant taxa and habitat remain poorly understood. Many states of India are still in need of further investigations for Plants-AMF association. So, research work should be taken in these states and morphological characterization of AMF isolates should be followed by molecular and biochemical characterization. Indian researchers envisage such pioneering studies shortly. The taxonomy of Glomeromycota is presently in considerable flux with conflicting morphological and molecular data sets and the phylum for AMF has been revised several times (Morton and Redecker, 2001; Schüßler *et al.*, 2001). Phylogenetic analysis for classification must be resolved using criteria other than and in addition to morphology and ribosome encoding genes. It is therefore important and urgent for Indian scientists to also utilize and expand on new molecular tools to explore both classification and distribution of AMF species in roots and soil.

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