Chapter 2
Advances in Arbuscular Mycorrhizal Taxonomy


2.1 Introduction

Taxonomy, the science of classifying organisms, describes names, identifies organisms, and generates tools for taxonomic identification of fungi. A review article by Shenoy et al. (2007) compiled the main activities of fungal systematics. The products of taxonomy are used by taxonomists and ecologists (Hodkinson and Parnell 2007). Correct species names are deliberately used for instance on land management systems to compare ecological interactions between the different components.

Current classification systems of Arbuscular mycorrhizal fungi (AMF, Glomeromycota) involve both morphological and molecular tools and their progress shows in some measure a natural organization and understanding of the relationships among species. Several research groups have been discussing the taxonomy,
systematics, and evolution of AMF. The researchers may propose their classification system; however, most biologists believe that these developing systems only reflect our knowledge at time (Goto 2014). This chapter presents an overview of data showing AMF classification, and recent advances are here compiled. Our goal was to provide nonspecialists such as researchers in other fields and land managers with information on historical and recent changes in AMF classification.

2.2 Advances in AMF Taxonomy

Taxonomy, the identifies and describes names, generating tools for taxonomic identification of fungi. The products of taxonomy (species lists, descriptions of formally delimited species, and identification keys, among others) are used by taxonomists and ecologists (Hodkinson and Parnell 2007). As previously stated, a review article by Shenoy et al. (2007) compiled the main activities of fungal systematics before and after the twentieth century.

With regard to the classification of AMF, it was based mostly in the spore morphologies (see Morton et al. 2004; Stürmer 2012). However, delimitation of taxa is very difficult and new information is continuously added. Stürmer (2012) reviewed the AMF systematics suggesting four periods, which the phylum Glomeromycota (Schüßler et al. 2001) has passed, that is, the discovery, alpha taxonomy, cladistics, and phylogenetic synthesis periods. The increasing AMF species reported within the course of time are shown in Table 2.1. One of the most widely accepted classification system for AMF proved to be that of Oehl et al. (2011a, b) (Table 2.2), who intended a further division of three AMF classes and the establishment of a fifth order, namely Gigasporales. They based their classification system on morphological (such as spore morphology and spore formation, and mycorrhizal and mycelial structures including staining processes) and genetic features (β-tubulin and rRNA sequences). A few important advances have been presented since then, e.g., in the Glomerales (e.g., Sieverding et al. 2014; Błaszkowski et al. 2015), in the Gigasporales (Silva et al. 2012; Pontes et al. 2013; Marinho et al. 2014), in the Diversisporales (Błaszkowski 2012; Medina et al. 2014), and in the Archaeosporales (Oehl et al. 2015). Therefore, we suggest the classification proposed by Oehl et al. (2011a) including the most recent progress for better understanding of the natural classification of AMF (see also Aguilera et al. 2015; www.agroscope.ch/saf).

Table 2.1 Number of arbuscular mycorrhizal species reported by periods

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of AMF species</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>2001–2011</td>
<td>65</td>
<td>Oehl et al. (2011a)</td>
</tr>
<tr>
<td>2012 to present</td>
<td>~40</td>
<td>Goto (2014)</td>
</tr>
<tr>
<td>Total of species</td>
<td>~270</td>
<td>Goto (2014)</td>
</tr>
</tbody>
</table>
Additionally, fungal taxonomists have recently integrated the modernization of its nomenclatural rules. The prerequisites of Latin descriptions, endorsement of electronic publication, and the use of the dual system of nomenclature (different names for the sexual and asexual phases of pleomorphic species) have ceased to be used (Hibbett and Taylor 2013).

### 2.3 Implications

In 2009, a total of 214 AMF species were described simply by morphological tools (few of them were successfully cultured) (Krüger et al. 2009). However, molecular characterization and morphological observations showed that AMF diversity is greater than the present estimations (Kottke et al. 2008; Öpik et al. 2008; Sudová et al. 2015).

A robust system of AMF classification will facilitate the research for specialists and nonspecialists (Table 2.3). There is a need to further explore the natural and nonnatural ecosystems for so far unknown AMF species and to describe them. This is for instance because almost all reports include a significant number of

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### Table 2.2 Some recent reviews and papers dealing with arbuscular mycorrhizal fungi classification, identification, and phylogeny

<table>
<thead>
<tr>
<th>Focus</th>
<th>References</th>
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<tbody>
<tr>
<td>DNA-based detection and identification of Glomeromycota</td>
<td>Öpik et al. (2013)</td>
</tr>
<tr>
<td>Classification of arbuscular mycorrhizal fungi</td>
<td>Redecker et al. (2013)</td>
</tr>
<tr>
<td>Systematic and phylotaxonomy of arbuscular mycorrhizal fungi</td>
<td>Krüger et al. (2012)</td>
</tr>
<tr>
<td>A molecular guide to the taxonomy of arbuscular mycorrhizal fungi</td>
<td>Young (2012)</td>
</tr>
<tr>
<td>A history of the taxonomy and systematics of arbuscular mycorrhizal fungi</td>
<td>Stürmer (2012)</td>
</tr>
<tr>
<td>Glomeromycota taxonomy</td>
<td>Oehl et al. (2011a)</td>
</tr>
<tr>
<td>Advances in Glomeromycota taxonomy</td>
<td>Oehl et al. (2011b)</td>
</tr>
<tr>
<td>Molecular phylogeny, taxonomy, and evolution of <em>Geosiphon pyriformis</em> and arbuscular mycorrhizal fungi</td>
<td>Schüßler (2002)</td>
</tr>
</tbody>
</table>

*Review

### Table 2.3 Journal articles dealing with arbuscular mycorrhizas and their taxonomy and ecology

<table>
<thead>
<tr>
<th>Key words</th>
<th>Number of journal articles</th>
</tr>
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<tbody>
<tr>
<td>AMF</td>
<td>&gt;4800</td>
</tr>
<tr>
<td>AMF+ecology</td>
<td>&gt;450</td>
</tr>
<tr>
<td>AMF+taxonomy</td>
<td>&gt;100</td>
</tr>
<tr>
<td>New AMF species</td>
<td>129</td>
</tr>
</tbody>
</table>

Database survey conducted on April 2015 (SCOPUS database since 1947) and other bases; AMF, arbuscular mycorrhizal fungi
non-identified AMF species, often attributed to the genus *Glomus*, but also in other genera, such as *Acaulospora* and *Gigaspora*, we are still aware of several to many unidentified species (e.g., Velázquez and Cabello 2011; Zangaro et al. 2013; Silva et al. 2014; Coutinho et al. 2015). Such studies will facilitate the AMF identification in the different studied ecosystems as well as their utilization and management. AMF biodiversity in natural ecosystems such as tropical forests or permanent grasslands is typically higher than in conventional agricultural systems, because of higher number of plant species and more complex habitats that can support a wider diversity. In tropical regions such as Brazil the number of accepted new AMF species is increasing (Błaszkowski et al. 2013; Goto et al. 2013; Mello et al. 2013; Lima et al. 2014). Also in regions with few studies, such as aquatic sites with macrophytes, new AMF species such as *Rhizoglomus melanum* are found (Sudová et al. 2015).

Since 1990, when molecular analyses to AMF species identification have started (Table 2.1), more new AMF species (~143, Goto 2014) have been described than in the previous 150 years (~127) (Schenck and Perez 1988). Some authors estimate that the number of species can reach 300–1600 (Ópik et al. 2013; Kivlin et al. 2011; Sudová et al. 2015). The discovery, isolation, and morphological/molecular description of new species to science are required due to increase of environmental impacts in preserved areas, as well as the potential uses of these fungi as bio-inoculants (Sieverding et al. 2014). In this sense, studies need a better assessment of the AMF communities in natural, managed reforested and agronomic areas (Fig. 2.1).

Fig. 2.1 Spores of non-identified, difficult to identify, and recently identified AMF species found in field conditions: clockwise from upper left: unidentified spore, *Septoglomus furcatum* identified from semiarid region of Brazil, *Acaulospora* sp. found in Minas Gerais, and *Fuscata aurea* from Amazonia. Photo credit: M. Pagano; Camilla M.R. Pereira
2.4 Conclusion

We briefly described advances in AMF classification based on both morphological and molecular characters and faster progress attained. We have mentioned that different research groups naturally adopt their preferred taxonomic system, which have been steadily improved by newly acquired knowledge. The different systems, however, have been approaching each other due to the concomitant progresses on morphological and molecular characterization of species belonging to the phylum. Both morphological and molecular characterization have still to be developed further. Moreover, a large portion, and probably the majority, of AMF species have still remained undiscovered and undescribed. Thus, AMF taxonomy and classification consequently have to develop further for at least another 50–100 years on both lower and higher taxon levels attempting to diminish the current knowledge gaps.

An advanced Glomeromycota system will facilitate ecological research and efforts to accrue benefits from mycorrhizas. Consequently, a better diagnosis of new AMF species will help to achieve maximum benefits from these microorganisms.

References


Recent Advances on Mycorrhizal Fungi
Pagano, M.C. (Ed.)
2016, VI, 147 p. 17 illus., 12 illus. in color., Hardcover
ISBN: 978-3-319-24353-5