Wild mushrooms in Ethiopia: A review and synthesis for future perspective

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Abstract
Aim of study: To review and provide all-purpose information about wild mushrooms in Ethiopia and to create awareness for conservation and use of mycological resources.

Area of study: We focused mainly on Ethiopia, where information about wild mushrooms is scanty and their status is unknown under the rampant degradation of the habitats.

Main results: We reviewed all relevant references related to wild mushrooms and their ecological niches, cultural practices and species used for cultivation as well as the anthropogenic factors affecting the conservation of fungal diversity.

Research highlights: This review summarizes issues related to the diversity of wild mushrooms, the main ecological niches and their associated fungal species, and mushroom cultivation practices in Ethiopia. Moreover, threats and the need for future conservation of wild mushrooms in the country are also reported. This review paper can serve as base line information and indicator for further mycological studies in Ethiopia as well as in other developing countries with similar scenarios.

Keywords: Diversity; ecological niches; Ethiopia; mushroom cultivation; wild mushrooms.

Introduction
Wild mushrooms are either epigeous or hypogeous heterotrophic organisms that belong to the Basidiomycota and Ascomycota divisions (Chang & Lee, 2004; Crous et al., 2006). Many of the wild mushroom species are becoming important parts of the livelihoods of rural people in different parts of the world (Sarma et al., 2010; Cai et al., 2011), being collected as valuable Non Timber Forest Products (NTFPs) (Chang & Lee, 2004; Boa, 2004). They help people to reduce vulnerability to poverty and strengthen the livelihoods through a reliable source of income. Globally, about 140,000 important mushroom species have been reported (Boa, 2004). These can serve as sources of food (Boa, 2004), medicine (Ferreira et al., 2010), enzymes and various industrial compounds (Gryzhenhout et al., 2010).

Pegler & Rayner (1969) and Pegler (1977) noted that the East Africa region is rich in macrofungal species. Many of these species are presumed to be either cosmopolitan or to be widespread across Africa (Pegler, 1977; Munyanziza, 1994). Like other East African countries, Ethiopian fungal flora remains unexplored (Sitotaw et al., 2015b; Munyanziza, 1994). Many of these species are presumed to be either cosmopolitan or to be widespread across Africa (Pegler, 1977; Munyanziza, 1994). Like other East African countries, Ethiopian fungal flora remains unexplored (Sitotaw et al., 2015b), as most regions and habitats in the country have been seldom studied (Sitotaw et al., 2015a). Reports regarding wild mushroom diversity rarely exist (Sitotaw et al., 2015b; Megersa et al., 2017). This is due to a lack of research infrastructures as well as to a lack of fungal taxonomists and specialists in fungal ecology (Osarenkhoe et al., 2014). Finally, and likely as a result, fungi are not included in the biodiversity database of the country (IBC, 2005). This poor knowledge on Ethiopian fungal species is worrying as fungi are highly sensitive towards habitat disturbances, namely anthropogenic threats that are rife across the country (IBC, 2005; Goldmann et al., 2015).

Despite poor scientific knowledge on fungal diversity, wild mushroom hunting and utilization is a traditional common practice among the different tribes in the country (Tuno, 2001; Semwal et al., 2014). Mushrooms
have been used for their nutritional, traditional and medicinal properties, and are also involved in local mythology (Tuno, 2001; Abate, 2014). Equally to other wild edibles, they have also been used as a coping food during food shortage periods (Lulekal et al., 2011, Alemu et al., 2012). In some local markets mushrooms are also available (Abate, 2014), where they are sold by the local people to earn some income to supplement the household economy.

In this review, we aimed to provide basic information about wild mushrooms in Ethiopia by assessing the available documents and to create awareness for conservation and a wider use of mycological resources in the country. This paper aims to serve as a basic document for further mycological studies in the country, and elsewhere in the region with similar scenarios.

Diversity of wild mushrooms

Functionally wild mushrooms are categorized as saprophytes, that obtain nutrients from dead organic materials; parasitic which depend on living plants and mycorrhizal, that form associations with host plants from which each partner gets benefits from each other (Ferris et al., 2000).

Mushrooms also tend to be linked to the vegetation of an area. Hence, understanding the ecology of host or keystone species helps to find the possible associated taxa in any habitat (Härkönen et al., 2003). In Ethiopia there are diverse habitats (Frisi et al., 2010) characterized by a high richness of species, including the fungi (Sitotaw et al., 2015b). However, the published literature to which we had access lack to portrait the country’s mycoflora profile but only focuses on a handful of species. Here we summarize and present a short overview of wild mushrooms and their related habitats in Ethiopia (Table 1). The discussion analyses the following categories: (1) mushrooms in indigenous forests, (2) mushrooms in grazing lands, (3) mushrooms in termite mounds and (4) mushrooms in exotic tree plantations.

Mushrooms in indigenous forests

Indigenous forests are a typical part of Ethiopian landscape (Frisi et al., 2010), covering a range of environments. The occurrence of mushrooms in these forests is widespread during the rainy season (Abate, 2014). Some taxa like Lentinus spp. are also unique as they fruit during the dry season (Tuno, 2001).

The most important scholar references on fungal diversity come from the comprehensive works of Hjortstam & Ryvarden (1996) who reported fifteen Corticiaceae species (List of species not given), of which Mycoacia brunoefusca and Vuilleminia obducens were new to science. Decock et al. (2005) also reported a total of four taxa from the highland forests region, and of which Fomitiporia tenuis and F. aethiopica were newly reported to the world. Some other taxa have also been reported by Tuno (2001), Abate (2008), Alemu (2013), Muleta et al. (2013), Abate (2014) and Sitotaw et al. (2015a) from indigenous forests in different parts of the country.

Most recently, Megersa et al. (2017) reported 49 fungal taxa from Degaga natural forest in three years of collections (Complete list of the taxa not given). Also, our research team collected 64 macrofungal species in a single rainy season, suggesting the presence of moderate diversity of fungi in the dry Afromontane forests in the Southern region (Pers.obs). Interestingly, some of the taxa like Agaricus spp., Agrocybe spp., and Calvatia spp. in our collections could only be identified at the genus level, while some others couldn’t be identified at all, indicating the likely presence of species new to science. Based on a survey report of NTFPs from the Benishangul Gumz Region, Alemu et al. (2012) also reflected a wider diversity of macrofungal species in Western dryland forests. The species reported there were described using local names only and lack their precise Latin names.

All of the taxa reported in indigenous forests were saprophytic (Table 1). Unfortunately, most valuable ectomycorrhizal (ECM) species common in African forests like Lactarius spp. and Amanita spp. (Okhuoya et al., 2010), were not reported in any of the references assessed. This was not surprising as most of the tropical woody tree species are unable to form associations with ECM fungi (Brundrett, 2009), particularly those indigenous tree species of Ethiopia.

Mushrooms in grazing areas

Upland grazing areas are found on the highland plateaus about 2000-3000 m above sea level. The farming systems in these areas are characterized by livestock rearing in addition to crop production. Abate (1999), Alemu (2013), Abate (2014) and Sitotaw et al. (2015a) cited some taxa in these areas. The saprophytic species belong to the genus Agaricus spp. was the dominant so far reported in the upland grazing areas. Despite valuable, the diversity of fungal species in Ethiopian grazing lands might be a lot richer than what has been so far reported; something that further complementary studies could confirm.

Mushrooms associated with termites

The symbiotic association of Termitomyces fungal species with termites is a remarkable example of the
Table 1. Resum of taxa of wild mushrooms reported so far from Ethiopia and with reference to their associated habitats.

| List of taxa                  | Habitat | Sources                                      |
|-------------------------------|---------|----------------------------------------------|
| Agaricus arvensis Schaeff.    | NF, GA  | Abate (2014), Alemu (2013)                   |
| Agaricus campestris L.        | NF, GA  | Abate (1999), Abate (2008), Alemu (2013), Sitotaw et al. (2015a) |
| Agaricus xanthodermus Callac & Guinb. | GA     | Sitotaw et al. (2015a)                       |
| Agaricus xanthodermus Genev.  | GA      | Sitotaw et al. (2015a)                       |
| Amanita spp. Pers.            | No avail| Megersa et al. (2017)                        |
| Armillaria spp. (Fr.) Staud   | NF      | Abate (2008), Abate (2014)                   |
| Auricularia spp. Bull. exJuss.| NF     | Abate (2008), Abate (2014)                   |
| Bjerkandera adusta (Wild.) P. Karst. | No avail | Megersa et al. (2017)                        |
| Catathelasma ventricosum (Peck) Singer | No avail | Megersa et al. (2017)                        |
| Chlorophyllum molybdites (G. Mey.) Massee | NF, PT | Abate (2008), Abate (2014), Megersa et al. (2017) |
| Clitocybe nuda (Bull.) H.E. Bigelow & A.H. Sm. | NF | Megersa et al. (2017)                        |
| Coprinus spp. Pers.           | NF      | Abate (2014)                                 |
| Corticiaceae spp. Herter      | NF      | Hjortstam & Ryvarden (1996)                  |
| Craterellus spp. Pers.        | No avail| Megersa et al. (2017)                        |
| Dicryptophora indusiata (Vent.) Desv. | NF     | Tuno (2001)                                  |
| Diplomitoporus rimosus (Murrill) Gilb. & Ryvarden | NF | Hjortstam & Ryvarden (1996)                  |
| Fomitiporia aethiopica Decock, Bitew & G. Castillo | NF | Decock et al.(2005)                         |
| Fomitiporia pseudopunctata (A. David, Dequatre & Fiasson) Fiasson | NF | Decock et al.(2005)                         |
| Fomitiporia robusta (P. Karst.) Fiasson & Niemelä | NF | Decock et al.(2005)                         |
| Fomitiporia tenuis Decock, Bitew & Castillo | NF | Decock et al.(2005)                         |
| Gymnopilus spp. P.Karst.      | No avail| Megersa et al. (2017)                        |
| Gymnopilus eucalyptorum (Pers.) Roussel | No avail | Megersa et al. (2017)                        |
| Geastrum triplex Jungh.       | No avail| Megersa et al. (2017)                        |
| Gyromitra spp. Fr.            | NF      | Alemu (2013)                                 |
| Hypholoma spp. (Fr.) P.Kumm.  | NF      | Abate (2008)                                 |
| Lentinellus sulphureus (Bull.) Murrill | NF | Abate (2008), Muleta et al. (2013), Abate (2014) |
| Lentinus spp. Fr.             | NF      | Tuno (2001), Abate (2008)                    |
| Lenzites betulina (L.) Fr.    | No avail| Megersa et al. (2017)                        |
| Lepista spp. (Fr.) W.G. Sm.   | No avail| Megersa et al. (2017)                        |
| Macrolepiota procera (Scop.) Singer | No avail | Megersa et al. (2017)                        |
| Macrolepiota spp. Singe       | NF, GA  | Abate (2008), Abate (2014)                   |
| Morchella esculenta (L.) Pers. | No avail| Megersa et al. (2017)                        |
| Mycociaca brunneofusca Hjortstam & Ryvarden | NF | Hjortstam & Ryvarden (1996)                  |
| Onnia tomentosa (Fries) P. Karsten | No avail | Megersa et al. (2017)                        |
| Phallales spp. E. Fisch       | NF      | Tuno (2001)                                  |
| Phellinus populicola Niemelä  | No avail| Megersa et al. (2017)                        |
| Pholiota adipose (Fr.) P. Kumm. | No avail | Megersa et al. (2017)                        |
| Pholiota spp. (Fr.) P. Kumm.  | NF      | Abate (2014)                                 |
coexistence of fungi with insects (Frøslev et al., 2003; Yamada et al., 2005; Damian, 2012). The fungus produces small nodules, which are consumed by termites along with the degraded substrate piles, named combs. During rainy periods, the mycelium that grows degrading the termite combs produces mushrooms, which penetrate the termite nests and soil to reach the surface and thus spread their spores (Frøslev et al., 2003). In Ethiopia, most of the Termitomyces fungal species (Table 1) are reported from the lowland areas of the country, where termite mounds are more abundant (Muleta et al., 2013; Abate, 2014; Sitotaw et al., 2015b; Megersa et al., 2017).

Table 1. Continued

| List of taxa                                | Habitat | Sources                                      |
|---------------------------------------------|---------|----------------------------------------------|
| Physisporinus rivulosus (Berk. & M.A. Curtis) Ryvarden | NF      | Hjortstam & Ryvarden (1996)                  |
| Polyporus cinnabarinus (Jacq.) Fr.          | No avail| Megersa et al. (2017)                         |
| Polyporus spp. P. Micheli ex Adans.        | NF      | Alemu (2013)                                 |
| Polyporus squamosus (Huds.) Fr.            | No avail| Megersa et al. (2017)                         |
| Pycnoporus spp. P. Karst.                  | NF      | Alemu (2013)                                 |
| Ramaria stricta (Pers.) Quél.              | No avail| Megersa et al. (2017)                         |
| Russula spp. Pers.                         | No avail| Megersa et al. (2017)                         |
| Schizophyllum commune Fr.                  | NF      | Tuno (2001), Abate (2008), Alemu (2013)      |
| Stereum rugosum Pers.                      | No avail| Megersa et al. (2017)                         |
| Suillus luteus (L.) Roussel                | PT      | Abate (2008)                                 |
| Termitomyces aurantiacus (R. Heim) R. Heim | TM      | Sitotaw et al. (2015b)                        |
| Termitomyces clypeatus R. Heim             | TM      | Muleta et al. (2013), Sitotaw et al. (2015b) |
| Termitomyces eurrhizus (Berk.) R. Heim     | No avail| Megersa et al. (2017)                         |
| Termitomyces eurrhizus (Berk.) R. Heim     | TM      | Sitotaw et al. (2015b)                        |
| Termitomyces leetstui (Pat.) R. Heim       | TM      | Sitotaw et al. (2015b)                        |
| Termitomyces microcarpus (Berk. & Broome) R. Heim | TM | Muleta et al. (2013), Abate (2014), Sitotaw et al. (2015b) |
| Termitomyces robustus (Beeli) R. Heim      | TM      | Sitotaw et al. (2015b)                        |
| Termitomyces schimperi (Pat.) R. Heim      | TM      | Sitotaw et al. (2015b)                        |
| Thelephora terrestris Ehrh.                | No avail| Megersa et al. (2017)                         |
| Trametes gibbosa (Pers.) Fr.               | No avail| Megersa et al. (2017)                         |
| Trametes versicolor (L.) Lloyd             | NF, PT  | Alemu (2013), Megersa et al. (2017)           |
| Trichaptum biforme (Fr.) Ryvarden          | No avail| Megersa et al. (2017)                         |
| Vascellum spp. F. Marda                   | GA      | Abate (2008)                                 |
| Vuilleminia obductens Hjortstam & Ryvarden| NF      | Hjortstam & Ryvarden (1996)                  |

GA: grazing area, NF: natural forest, TM: termite mounds and PT: plantation forest. No avail: habitat not available in the document. Fungal taxa names and authors’ names were obtained from Mycobank database (http://www.mycobank.org).

Mushroom in exotic tree plantations

Plantation forests are dominated by exotic tree species, mainly of the Eucalyptus, Cupressus, Pinus and Acacia genera (Bekele, 2011). The mass introduction and expansion of these trees in the country implies as a consequence, the indirect introduction of associated exotic fungal species too. This is the case of several ECM mushrooms (Table 1) originated from Mediterranean and temperate climates associated with these non-native trees (Megersa et al., 2017). For example, Suillus luteus is common in Pinus tree species plantations (Abate, 2008). Such mushroom species have a potential to diversify the value of plantation forests through mycosilvicultural management approaches (Boa, 2004; Peredo et al., 1983) and can be produced in high quantities.

Mushroom cultivation

Mushroom cultivation can contribute towards the goal of habitat conservation and food security. Around the world about 60 mushroom species have been cultivated commercially (Chang & Miles, 2004). The most common ones include Agaricus bisporus, Lentinula edodes, Pleurotus ostreatus, Flammulina velutipes, Volvariella volvacea, Grifola frondosa,
and Pholiota nameko (Gizaw, 2010). In Ethiopia, the practice of mushroom cultivation is a recent activity, mostly restricted to urban areas (Yehuala, 2008; Abate, 2014). Agricultural and agro-industrial wastes have been used at a small scale to produce four most commonly cultivated mushrooms: A. bisporus, L. edodes, P. ostreatus (Yehuala; Gebrelibanos et al., 2016) and P. florida (Gebrelibanos et al., 2016). The levels of essential and non-essential metals in cultivated mushrooms such as P. ostreatus and P. florida were also studied in Haramaya, Oromia Region (Gebrelibanos et al., 2016). However, lack of awareness and cultivation skills still leave plenty of room for improvement and growth regarding mushroom cultivation (Yehuala, 2008; Muleta et al., 2013).

Owing to their flavor and nutritional value, the consumption of cultivated mushrooms is now constantly increasing, particularly in the main cities. On the other hand, conservative eating habits are also hindering the transfer of cultivation technology at a local level, particularly in areas where mushroom consumption is not a common practice.

Threats and the need for conservation

Many threats affecting wild mushrooms are similar to those that globally affect the biodiversity in Ethiopia (IBC, 2005). The most important of all, deforestation, comes as a consequence of anthropogenic change to which global environmental and climate change also add (Lulekal et al., 2011). According to Teketay (2001), deforestation is immense and estimated between 150000 – 200000 ha of land per year. Factors contributing to habitat degradation, such as fires, are also affecting the fungal communities in forest systems (Vásquez-Gassibe et al., 2016), which is also a recurrent phenomenon in the natural forest systems in the country. This adversely influences the macrofungi and diminishes their diversity and production (Miller & Lodge, 1997). Such impact also limits the benefits that can be obtained from fungal resources. Thus, urgent conservation strategies and actions are needed, giving special considerations to those species currently used by the local people.

Conclusions and prospects

The reviewed references in this document highlight the existence of a valuable mycoflora in Ethiopia. Also, reveal some ecological niches in which important wild mushrooms exist. However, they miss to portrait the fungal diversity profiles in the country overall. Some of the taxa reported in some references are also not properly identified as they are only registered with their local names (Alemu et al., 2012). This also applies to other countries in the Region that supposed to have high potential linked to this natural resource as well, and reveals the need to accomplish thorough scientific studies in order to get a glimpse of the vast number of fungal species across the Region. Furthermore, the status of many wild mushroom species is also unclear, as habitat degradation is immense. We believe that further studies involving close examinations of different habitats are needed, since there might be yet unknown species with valuable potential but equally unknown uses.

According to our review, many are the possible options to widen the cultivation of mushrooms at small and large scales. At a small-scale level, homestead cultivation is possible using locally available substrates. Plantation forests in Ethiopia and also in others countries in the region could provide opportunities to introduce important mushroom species and can be used for large scale cultivation purposes. Globally highly appreciated taxa such as Boletus pinophilus, B. edulis and Lactarius deliciosus could be produced in plantation forests by means of seedling mycorrhization (Högberg & Pearsce, 1986; Perry et al., 1987; Águeda et al., 2008; Mediavilla et al., 2016). Thus, adopting and scaling up of mycorrhization technologies may offer incentives for widening mushroom cultivation practices. This could also be a major future research area. Also, wood waste could be used (Sefidi & Etemad, 2015) to cultivate important medicinal species such as Pleurotus ostreatus, Ganoaderma lucidum and Coriolus versicolor in natural and plantation forest systems.

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