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SOIL ZYGOMYCETOUS FUNGI IN BIEBRZA NATIONAL PARK (NORTHEAST POLAND)*

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Abstract. Although zygomycetous fungi are frequently isolated from forest soils, little is known about their diversity in peatland soils. We assessed the diversity of soil zygomycetes in Biele Suchowolskie fen after a long-lasting fire and compared it with previous reports on peatland soil fungi. The zygomycetous assemblage of the Biebrza mires appeared to be diverse and unique, due to the absence of some common species and the accumulation of species sharing specific characters of sporangia morphology.

Key words: Zygomycota, Kickxellales, Mortierellales, Mucorales, peatland, Biebrza National Park

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INTRODUCTION

Peatland is a general term describing an area with natural accumulation of peat layer at the surface (Joosten & Clarke 2002). Peatland covers *ca* 3% of the Earth's terrestrial and freshwater surface, most of it located in the Northern Hemisphere (Joosten & Clarke 2002). Most peatlands have been strongly affected by human activity in recent centuries, especially by drainage for agricultural or forestry purposes (Strack 2008). As peat has high carbon content of at least 30% of its dry mass (Joosten & Clarke 2002), meliorated peatlands can easily burn under low moisture conditions and subsequently smolder for long periods of time (Kuhry 1994). Because of the importance of these areas for sustaining global biodiversity, in 2003 the Ramsar Convention promulgated 'Guidelines for Global Action on Peatlands' in order to promote their global conservation. Although these guidelines also emphasize the need to inventory peatlands, still relatively little is known about the diversity of microfungi in peatland ecosystems. Thanks to growing interest in the role of peatland soil fungi in the global carbon cycle under changing climate (Blodau 2002), some basic research on this subject has been done in the last ten years (Thormann *et al*. 2003; Thormann 2006; Thormann & Rice 2007). In their extensive literature review, Thormann and Rice (2007) gave a summary of all species of peatland fungi, compiled from a wide range of peer-reviewed mycological publications and internet databases. There were 276 ascomycetous fungi reported from peatlands, but they comprise only 0.4% of all species within Ascomycota, while the 55 zygomycetous species found in peatlands represent more than 5% of all species within Zygomycota. *Mucor* (13 species), *Mortierella* (20) and *Umbelopsis* (5) are the dominant zygomycetous genera isolated from peatlands (Thormann & Rice 2007). *Mortierella alpina* Peyronel, *Mucor hiemalis* Wehmer, *Umbelopsis ramanniana* (Möller) W. Gams and *Umbelopsis vinacea* (Dixon-Stew.) Arx are the most

* This paper is dedicated to Professor Tomasz Majewski on the occasion of his 70th birthday.

frequently reported species (Thormann & Rice 2007). Thus, the dominant zygomycetous species appear similar to those from forest ecosystems on mineral soil (Domsch *et al.* 1993).

One of the largest and most well-preserved peatland areas in the European Temperate Zone is Biebrza National Park, which is protected under the Ramsar Convention (Gwiazdowicz & Klemt 2004). Although there are numerous works on the plant and animal biodiversity of this region (Banaszuk 2004), the soil microfungi of Biebrza peatlands have been analyzed only by Tyszkiewicz (2004 a, b). In 2002, 1030 ha of the Biele Suchowolskie fen in Biebrza National Park burned due to desiccation resulting from drainage (Kania *et al.* 2006). This deep-seated, long-lasting fire influenced hydrological conditions (Mętrak *et al.* 2008), considered one of the most important factors shaping wetland habitats (Tołpa *et al.* 1967; Pałczyński 1975). Recent research showed that even short-term perturbations in moisture conditions can change the microbial community (Kim *et al.* 2008). Such significant changes in fungal community composition after drainage were confirmed by Peltoniemi *et al.* (2009), who also showed that basidiomycetes are more sensitive to hydrological changes than ascomycetes; however, they did not interpret the data on zygomycetes from drained peatlands.

Traditionally, the phylum Zygomycota is divided into two classes: Zygomycetes and Trichomycetes (White *et al.* 2006). In recent taxonomic studies this polyphyletic phylum is subdivided into four monophyletic groups: Mucoromycotina, Kickxellomycotina, Zoopagomycotina and Entomophthoromycotina (Hibbett *et al.* 2007). In this paper we keep the term Zygomycota to determine all genera and species traditionally included in this group. The phylum comprises over 1000 species, ubiquitously distributed worldwide (Kirk *et al.* 2008) and including common saprobionts in soil and dung as well as facultative or obligate parasites (Benjamin 1979).

The main purpose of the present study was to determine the diversity of soil- and litter-inhabiting zygomycetous fungi from Biele Suchowolskie fen in Biebrza National Park (Poland) after a severe long-lasting fire. We also compared this diversity with findings from previous reports on peatland soil Zygomycota.

Materials and methods

The study was done in the area of Biele Suchowolskie fen in the middle basin of the Biebrza River within Biebrza National Park (Mętrak *et al.* 2008). In 2008, five study areas, 1 ha each, were designated (Kania *et al.* 2006; Mętrak *et al.* 2008; Wójcik 2010):

W2 – (53°36′N, 23°03′E) *Caricion nigrae* Koch 1926 *emend.* Klika 1934 alliance; moderately mucked peat-muck soil (Mt II); mean pH (in KCl) 6.58; periodically flooded; unburnt.

W3 – (53°38′N, 23°04′E) *Salicetum pentandro-cinereae* (Almq. 1929) Pass. 1961 association with *Urtica dioica* L.; moderately mucked peat-muck soil (Mt II); mean pH (in KCl) 6.39; moist; burnt.

W5 – (53°37′N, 23°02′E) *Filipendulion* alliance with *Deschampsia caespitosa* (L.) Beauv.; variable moisture conditions; mineral soil (no specific data) on mineral upland; unburnt.

W7 – (53°37′N, 23°03′E) wet meadow with *Festuca rubra* L.; moderately mucked peat-muck soil (Mt II); mean pH (in KCl) 6.29; very moist; unburnt.

W8 – (53°38′N, 23°03′E) *Salicetum pentandro-cinereae* association with *Urtica dioica* L.; moderately mucked peat-muck soil (Mt II); mean pH (in KCl) 6.28; moist; burnt.

In September 2008, 21 samples (1 kg each) from the top 20 cm of the soil, including litter and M_1 horizons (term after Dobrzański & Zawadzki 1995) were collected at each site and brought undisturbed to the laboratory in sealed plastic bags. In October 2009, 9 supplementary samples (100 g each) of surface soil (only M1 horizon) were taken at each site. In the laboratory, the litter and M_1 layers were analyzed independently. The soil microfungi were isolated by the soil dilution plate method on potato dextrose agar (Bills *et al*. 2004) and by Warcup soil plate techniques (Warcup 1950). The low-nutrient agar was also used to detect oligotrophic species (e.g., *Mortierella*). Litter samples from four sites (W2, W3, W7, W8) were tested with the moist chamber method in order to detect the microfungi growing obligately on leaf litter (Krug 2004). After three days of initial incubation at room temperature for up to one month, all emerging fungi were recorded and subsequently identified according to the available literature (Linder 1943; Linnemann 1953; Benjamin 1958; Benjamin 1959; Barnett 1960; Embree 1963; Mehrotra *et* *al.* 1963; Zycha *et al.* 1969; Mehrotra & Kakkar 1970; Chien 1971; Pidopliczko & Milko 1971; Milko 1974; Gams 1977; Skirgiełło *et al.* 1979; Domsch *et al.* 1993; Kwaśna *et al.* 1999a, b; Kwaśna *et al.* 2002; Zheng & Chen 2001; Watanabe 2002; Hoffmann *et al.* 2007). Digital images were recorded with a Nikon DX 1200 camera. Jaccard's similarity index was calculated using EstimateS (Colwell 2009).

RESULTS AND DISCUSSION

After analysis of 150 samples a total of 41 species of zygomycetes (including 39 exclusively from peat soil) were found in the soils from Biebrza National Park (Table 1). Only the literature review by Thormann and Rice (2007) gives more (50) zygomycetous species, but only 17 of those are on the list of species we found; our results add 22 taxa to the list of peat fungi they compiled. Among the isolates from Biebrza National Park, *Mortierella ambigua* B. S. Mehrotra and *Mortierella capitata* Marchal were recorded for the first time from Poland. There were also two species of *Coemansia* that could not be identified as known species according to Linder (1943), Badura and Badurowa (1964) or Kwaśna *et al*. (1999a, 2002). The first isolate, called '*Coemansia spiralis*-like' according to the key provided by Linder (1943), differs in many aspects from all species included in the 'spiralis complex' (Kwaśna *et al.* 2002). The second, '*Coemansia interrupta*-like' according to Linder (1943), differs in spore dimensions from the typical description of the species. As both *Coemansia* spp. were isolated only once, we do not describe them as new species.

Site W5 on mineral soil and W7 on peaty soil appeared to have the most diverse and richest communities of zygomycetes (Table 2). *Absidia caerulea* Bainier, *Absidia glauca* Hagem, *Mortierella elongata* Linnem. and *Mucor hiemalis* f. *corticola* (Hagem) Schipper were the most abundant species from Biebrza National Park (Table 2). As indicated by Jaccard's similarity index, the highest similarity of fungal communities was between sites W5 and W7 and between sites W7 and W8. Similarity was lowest between sites W2 and W3 (Table 3). These similarities do not correlate with the plant communities, hydrological conditions, or the occurrence of fire at the sites. Note, however, that sites W5, W7 and W8 are all close to each other, while W2 and W3 are the most distant from each other. We observed some patterns in the fungal communities: *A. caerulea* was typical of mineral soils, and on peat soils it was replaced by *A. glauca* (Fig. 1); both species are usually treated as ubiquitous saprobionts (Domsch *et al.* 1993).

The data in Table 1 show that several common Mucorales representatives are very rare or absent on the Biebrza mires. *Mucor plumbeus* Bonord., *Mucor racemosus* Bull. and *Zygorhynchus moelleri* Vuill., all of which are usually frequent in soil samples (Domsch *et al.* 1993; Jóźwiak 2008), appeared only occasionally. Instead, *Mucor varians* Povah, *M. hiemalis* f. *corticola, Mucor ramosissimus* Samouts. and *Mucor flavus* Schrank were the most common species. According to De Bellis *et al.* (2007), the plant community is the main factor shaping microfungal assemblages; there are no important differences in host preferences or nutritional requirements between the majority of the species enumerated above (Domsch *et al.* 1993).

Members of the family Umbelopsidaceae Meyer and Gams (2003), which are usually dominants in sandy or forest soils and in the rhizosphere of different trees (Domsh *et al*. 1993; Jóźwiak 2008), were also rare or not found in our samples from the Biebrza fens, as well as in Tyszkiewicz's (2004a, b) research. Krzemieniewska and Badura (1954b)

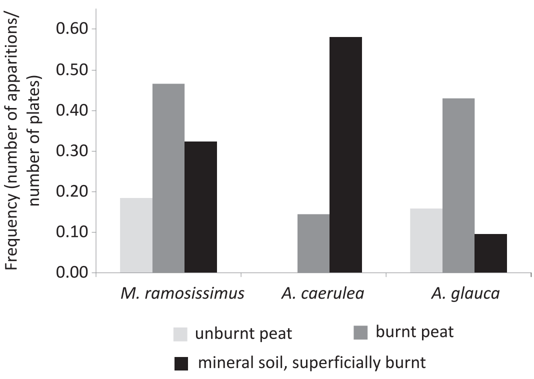


Fig. 1. Frequency of selected species at different sites in Biele Suchowolskie fen.

Table 1. List of zygomycetous fungi from Biele Suchowolskie fen, compared with data extracted from selected publications. Only taxa identified to species level are presented. Studies on peat soil are highlighted in grey. [1] present study, [2] Tyszkiewicz 2004a, b, [3] Krzemieniewska & Badura 1954a, [4] Krzemieniewska & Badura 1954b, [5] Badura & Badurowa 1964, [6] Jóźwiak 2008, [7] Thormann & Rice 2007, [8] Sampo *et al*. 1997, [9] Brown 1958, [10] Christensen & Whittingham 1965, [11] Soderstrom & Baath 1978, [12] Widden 1987, [13] Wicklow 1973, [14] Gochenaur & Backus 1967, [15] Gochenaur & Whittingham 1967, [16] Christensen *et al*. 1962, [17] Apinis 1964, [18] Christensen 1968, [19] Sewell 1959, [20] Morrall & Vanterpool 1968.

Site / Soil type Taxon	site W5, Poland, Biebrza National Park[1]	site W2, Poland, Biebrza National Park[1]	site W7, Poland, Biebrza National Park[1]	site W3, Poland, Biebrza National Park[1]	site W8, Poland, Biebrza National Park[1]	Poland, Biebrza National Park[2]	Poland, Muszkowice Reserve[3]	Poland, Muszkowice Reserve[4]	Poland, Lubsza Reserve[5]	Poland, Podkowa Leśna City Park[6]	compilation of literature[7]	Italy, Piedmont[8]	Great Britain, southern England[9]	USA, northern Wisconsin[10]	Sweden[11]	Great Britain, northern England[12]	USA, Wisconsin[13]	USA, southern Wisconsin[14]	USA, southern Wisconsin[15]	USA, southern Wisconsin[16]	Great Britain, England[17]	USA, northern Wisconsin[18]	Great Britain, England and Wales[19]	Canada, Saskatchewan[20]
	mineral	peat	peat	peat	peat	peat	mineral	mineral	mineral	mineral	peat	mineral	mineral	peat	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral
Absidia caerulea Bainier	+	–	–	+	+	–	–	–	+	+	+	+	+	–	–	–	–	–	–	+	+	–	+	–
Absidia cylindrospora var. *cylindrospora* Hagem	+	–	–	+	+	–	–	–	–	+	+	–	–	–	–	+	–	–	+	+	+	+	–	–
Absidia glauca Hagem	+	–	+	+	+	+	+	+	+	+	+	–	+	–	–	–	–	+	+	+	+	+	–	–
Absidia macrospora Váňová	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Absidia scabra Cocc.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Absidia spinosa var. *spinosa* Lendn.	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	+	–	–	+	–
Actinomucor elegans (Eidam) C. R. Benj. & Hesselt.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Backusella lamprospora (Lendn.) Benny & R. K. Benj.	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Circinella umbellata Tiegh. & G. Le Monn.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Coemansia aciculifera Linder	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–
Coemansia erecta Bainier	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Coemansia pectinata (Coem.) Bainier	–	–	–	–	–	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Coemansia reversa Tiegh. & G. Le Monn.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
'*Coemansia interrupta*-like'	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
'*Coemansia spiralis*-like'	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Coemansia thaxteri Linder	–	+	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cunninghamella elegans Lendn.	+	+	+	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–
Cunninghamella sp.	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–

Gongronella butleri (Lendn.) Peyronel & Dal Vesco	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–
Helicocephalum sp.	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Helicostylum pulchrum (Preuss) Pidopl. & Milko	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kickxella alabastrina Coem.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lentamyces parricida (Renner & Muskat *ex* Hesselt. & J. J. Ellis) K. Hoffm. & K. Voigt	+	–	+	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lichtheimia hyalospora (Saito) Kerst. Hoffm., Walther & K. Voigt	+	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lichtheimia corymbifera (Cohn) Vuill.	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lichtheimia ramosa (Zopf) Vuill.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella alliacea Linnem.	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Mortierella alpina Peyronel	–	–	+	–	+	–	–	–	+	+	+	+	+	–	+	–	+	+	+	–	+	–	–	+
Mortierella ambigua B. S. Mehrotra	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella bainieri Costantin	–	–	–	–	–	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella bisporalis (Thaxt.) Björl.	–	–	+	–	+	–	+	+	+	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–
Mortierella candelabrum Tiegh. & G. Le Monn.	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella capitata Marchal	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella dichotoma Linnem. *ex* W. Gams	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella echinula Linnem.	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Mortierella elongata Linnem.	+	+	+	+	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella exigua Linnem.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella gamsii Milko	–	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	–
Mortierella gemmifera M. Ellis	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella globulifera O. Rostr.	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella horticola Linnem.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella humicola Oudem.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella humilis Linnem. *ex* W. Gams	–	–	–	–	–	–	–	–	–	–	+	+	–	–	+	–	–	–	–	–	+	–	+	–
Mortierella hyalina var. *hyalina* (Harz) W. Gams	–	–	–	–	–	+	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	–	+	–
Mortierella jenkinii (A. L. Sm.) Naumov	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella lignicola (G. W. Martin) W. Gams & R. Moreau	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella macrocystis W. Gams	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–
Mortierella minutissima var. *minutissima* Tiegh.	+	+	+	–	+	+	–	–	–	–	+	–	–	+	–	–	–	+	+	–	–	–	+	–
Mortierella parvispora Linnem.	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	–	–	–	–	–	+	+	+	–
Mortierella pilulifera Tiegh.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella polycephala Coem.	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella pulchella Linnem.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–
Mortierella pusilla Oudem.	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella reticulata Tiegh. & G. Le Monn.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Mortierella sp.	+	+	+	+	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–

(cont.)

Table 1. *Continued.*

Taxon \ Site / Soil type	site W5, Poland, Biebrza National Park[1]	site W2, Poland, Biebrza National Park[1]	site W7, Poland, Biebrza National Park[1]	site W3, Poland, Biebrza National Park[1]	site W8, Poland, Biebrza National Park[1]	Poland, Biebrza National Park[2]	Poland, Muszkowice Reserve[3]	Poland, Muszkowice Reserve[4]	Poland, Lubsza Reserve[5]	Poland, Podkowa Leśna City Park[6]	compilation of literature[7]	Italy, Piedmont[8]	Great Britain, southern England[9]	USA, northern Wisconsin[10]	Sweden[11]	Great Britain, northern England[12]	USA, Wisconsin[13]	USA, southern Wisconsin[14]	USA, southern Wisconsin[15]	USA, southern Wisconsin[16]	Great Britain, England[17]	USA, northern Wisconsin[18]	Great Britain, England and Wales[19]	Canada, Saskatchewan[20]
	mineral	peat	peat	peat	peat	peat	mineral	mineral	mineral	mineral	peat	mineral	mineral	peat	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral
Mortierella stylospora Dixon-Stew.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella turficola Y. Ling	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella verrucosa Linnem.	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mortierella verticillata Linnem.	–	–	–	–	–	–	–	–	–	–	+	–	+	–	+	–	–	–	–	–	–	–	+	–
Mortierella zychae Linnem.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	+	–
Mucor circinelloides f. *griseocyanus* (Hagem) Schipper	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor circinelloides f. *janssenii* (Lendn.) Schipper	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Mucor circinelloides Tiegh.	+	+	+	–	+	–	+	–	–	+	+	–	–	–	–	+	–	–	–	–	–	–	–	+
Mucor flavus Bainier	+	+	+	+	+	–	+	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Mucor fragilis Bainier	+	–	+	+	+	–	–	–	+	–	+	–	–	+	–	–	–	+	+	–	+	–	–	–
Mucor genevensis Lendn.	–	–	–	–	–	–	+	–	+	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–
Mucor hiemalis f. *corticola* (Hagem) Schipper	+	+	+	+	+	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor hiemalis Wehmer	+	+	+	–	+	–	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+
Mucor hiemalis f. *silvaticus* (Hagem) Schipper	–	–	–	–	–	–	+	–	+	–	+	–	–	+	+	–	–	–	–	–	+	+	–	+
Mucor mucedo Fresen.	+	+	+	–	+	+	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor odoratus Treschew	–	–	–	–	–	–	+	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor piriformis A. Fisch.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor plasmaticus Tiegh.	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor plumbeus Bonord.	–	–	–	–	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mucor racemosus f. *racemosus* Fresen.	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor racemosus f. *sphaerosporus* (Hagem) Schipper	–	–	–	–	–	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–

Mucor racemosus Fresen.	+	–	+	+	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Mucor ramosissimus Samouts.	+	+	+	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor saturninus Hagem	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor strictus Hagem	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor subtilissimus Oudem.	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor varians Povah	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mucor zonatus Milko	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Parasitella parasitica (Bainier) Syd.	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Pilaira anomala (Ces.) J. Schröt.	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Piptocephalis cylindrospora Bainier	+	+	+	+	+	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	+	–	+	–
Piptocephalis dichotomica Krzemien. & Badura	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Piptocephalis fusispora Tiegh.	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Piptocephalis lepidula (Marchal) P. Syd.	+	–	+	–	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Piptocephalis microcephala Tiegh.	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Rhizopus arrhizus var. *arrhizus* A. Fisch.	+	+	+	–	+	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhizopus microsporus var. *microsporus* Tiegh.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–	–
Rhizopus stolonifer (Ehrenb.) Vuill.	+	+	+	–	–	–	+	+	+	+	+	–	–	–	–	–	–	–	+	–	–	–	–	–
Rhopalomyces elegans var. *elegans* Corda	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spiromyces minutus R. K. Benj.	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalastrum racemosum Cohn *ex* J. Schröt.	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–
Syncephalis aurantiaca Vuill.	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis cordata Tiegh. & G. Le Monn.	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis fasciculata Tiegh.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Syncephalis nodosa Tiegh.	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis pendula Tiegh.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–
Syncephalis penicillata Indoh	–	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis radiata Indoh	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis sphaerica Tiegh.	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syncephalis tenuis Thaxt.	–	–	–	+	–	–	+	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Syzygites megalocarpus Ehrenb.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Thamnidium elegans Link	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Umbelopsis angularis W. Gams & M. Sugiy.	–	–	–	–	–	–	–	–	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	+
Umbelopsis isabellina (Oudem.) W. Gams	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	–	–	–	+	–	–	+	+	+
Umbelopsis nana (Linnem.) Arx	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	+	+	–	+
Umbelopsis ramanniana (Möller) W. Gams	–	–	–	–	+	–	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	+	+	+
Umbelopsis vinacea (Dixon-Stew.) Arx	–	–	–	–	–	–	–	–	–	–	+	–	–	+	+	–	–	–	+	–	–	+	–	+
Zygorhynchus heterogamus (Vuill.) Vuill.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Zygorhynchus moelleri Vuill.	+	–	–	–	–	–	+	+	+	+	+	+	+	–	–	–	+	–	–	–	+	–	+	–
Total number of species	26	19	27	22	31	6	39	26	36	30	50	10	11	10	14	3	2	6	15	7	35	9	15	9

Table 2. Species abundance at sites W2, W3, W5, W7 and W8 in Biebrza National Park.

Taxon \ Site / Soil type		site W5	site W2	site W7	site W3	site W8
		mineral	peat	peat	peat	peat
1	*Absidia caerulea* Bainier	18	0	0	2	2
2	*Absidia cylindrospora* var. *cylindrospora* Hagem	6	0	0	3	1
3	*Absidia glauca* Hagem	3	0	6	8	4
4	'*Coemansia interrupta*-like'	0	1	0	0	0
5	'*Coemansia spiralis*-like'	0	0	0	0	1
6	*Coemansia thaxteri* Linder	0	1	0	0	1
7	*Cunninghamella elegans* Lendn.	4	4	10	4	3
8	*Cunninghamella* sp.	0	0	2	0	1
9	*Helicocephalum* sp.	0	0	0	1	0
10	*Lentamyces parricida* (Renner & Muskat *ex* Hesselt. & J. J. Ellis) K. Hoffm. & K. Voigt	2	0	4	6	1
11	*Lichtheimia hyalospora* (Saito) Kerst. Hoffm., Walther & K. Voigt	3	0	1	1	7
12	*Mortierella alpina* Peyronel	0	0	1	0	1
13	*Mortierella ambigua* B. S. Mehrotra	0	1	1	0	0
14	*Mortierella bisporalis* (Thaxt.) Björl.	0	0	1	0	1
15	*Mortierella capitata* Marchal	0	0	1	0	0
16	*Mortierella elongata* Linnem.	6	2	7	4	3
17	*Mortierella gamsii* Milko	0	1	0	2	2
18	*Mortierella minutissima* var. *minutissima* Tiegh.	2	1	1	0	2
19	*Mortierella* sp.	2	2	1	2	3
20	*Mortierella verrucosa* Linnem.	1	0	0	0	1
21	*Mucor circinelloides* Tiegh.	1	1	3	0	1
22	*Mucor flavus* Bainier	7	8	1	1	2
23	*Mucor fragilis* Bainier	2	0	1	1	1
24	*Mucor hiemalis* f. *corticola* (Hagem) Schipper	9	10	7	2	3
25	*Mucor hiemalis* Wehmer	4	2	2	0	1
26	*Mucor mucedo* Fresen.	4	1	2	0	2
27	*Mucor racemosus* Fresen.	2	0	2	2	0
28	*Mucor ramosissimus* Samouts.	10	5	2	5	8
29	*Mucor varians* Povah	2	4	4	2	1
30	*Pilaira anomala* (Ces.) J. Schröt.	0	0	0	2	2
31	*Piptocephalis cylindrospora* Bainier	3	1	1	2	1
32	*Piptocephalis lepidula* (Marchal) P. Syd.	4	0	1	0	1
33	*Piptocephalis microcephala* Tiegh.	2	0	1	1	0
34	*Rhizopus arrhizus* var. *arrhizus* A. Fisch.	2	13	4	0	1
35	*Rhizopus stolonifer* (Ehrenb.) Vuill.	5	5	3	0	0
36	*Syncephalis nodosa* Tiegh.	2	0	0	0	0
37	*Syncephalis penicillata* Indoh	0	1	0	1	1
38	*Syncephalis sphaerica* Tiegh.	0	0	5	1	3
39	*Syncephalis tenuis* Thaxt.	0	0	0	1	0
40	*Umbelopsis ramanniana* (Möller) W. Gams	0	0	0	0	1
41	*Zygorhynchus moelleri* Vuill.	1	0	0	0	0

reported that *Umbelopsis ramanniana* (Möller) Gams was a common fungus from beech forest on hill slopes (Central Poland) but was completely absent from stream valleys. Those results suggest that Umbelopsidaceae are absent from moist places. Marfenina (1999), however, stated out that this species disappears under anthropopression, so perhaps its absence can be explained by the

Table 3. Jaccard's similarity index for zygomycetous communities from Biebrza National Park.

	site W5	site W2	site W7	site W3	site W8
site W5	1				
site W2	0.424	1			
site W7	0.617	0.483	1		
site W3	0.470	0.322	0.441	1	
site W8	0.552	0.470	0.611	0.514	1

lack of some trees or shrubs stimulating fungal growth or synthesis pathways. Possibly members of Umbelopsidaceae are present on peat ground (as in Thormann & Rice 2007) but in places rich in species of the Ericaceae family. Perhaps ericaceous plants are factors stimulating Umbelopsidaceae growth on peatland. Sewell (1959) showed that *U. ramanniana* and *Umbelopsis isabellina* (Oudem.) W. Gams were especially frequent in heathland soil and in the rhizosphere of *Calluna* spp. In another study, *U. ramanniana* was often found in forestry cultivated soils (spruce nursery) but nearly absent from nearby agricultural cultivated soil (Hýsek & Brožová 2001). The influence of ericaceous plants as well as spruce and other trees on Umbelopsidaceae growth ought to be more closely examined.

At the beginning of sporogenesis the spores of a large number of zygomycetous species (e.g., *Piptocephalis microcephala* Tiegh., *Syncephalis sphaerica* Tiegh., *Coemansia* spp.) present in the Biebrza fens are very closely compacted in a sticky fluid forming a spore drop (Figs 3 & 4). Spores produced in sticky, mucilaginous masses are usually typical for insect-dispersed fungi (Deacon 2006). We found many nematodes, mites (Acarina), springtails (Collembola) and millipedes (Myriapoda) in our probes. Further research on insect-fungus interaction on peatlands would be useful in interpreting these results.

We conclude that the zygomycetous Mycota of the Biebrza fens is diverse, and unique for its absence of some common zygomycetous species (e.g., *U. isabellina*, *M. plumbeus*, *M. racemosus*) and the abundance of species characterized by spores liberated in sticky, mucilaginous masses.

Descriptions of some noteworthy strains from the Biele Suchowoslkie fen

'***Coemansia interrupta*-like'** Fig. 2

REFERENCES: Linder 1943.

NOTE. Colonies at first white, a few days later becoming straw yellow (Ridgway 2005); sporophores up to 8 mm long, 10–15 μm in diameter, distantly septate, irregularly branched in the upper part, branches fertile, bearing sporocladia, but also sterile; some branches very long with a short fertile region and with a sterile tip, the fertile region becoming somewhat zigzag; sporocladia long-stipitate, the stipe 1-celled and 10–15 μm long, sporocladia 25–32 μm long × 7–10 μm wide, 6–7 celled, with terminal cell sterile, curved; pseudophialides ovoid, with neck, 3 μm long; conidia yellow in mass, fusiform, 10–12 × 1.5 μm. According to Linder (1943) the spores as well as pseudophialides of *Coemansia interrupta* Linder are much longer [12.5–14.5(–18.0) × 2.5 μm and 5.5–7.0 × 3.5 μm respectively]. Moreover, our specimen was characterized by sporocladia emerging irregularly, at an acute angle from the sporophore, and they form nearly the same axis with the stipe cell, while Linder pointed out that the basal cells of sporocladia are angularly upturned in *C. interrupta* so that the sporocladia approximately parallel the main sporophore's axis.

SPECIMEN EXAMINED: plot W2, peat soil, Biebrza National Park, unburnt area.

'***Coemansia spiralis*-like'** Fig. 3

REFERENCES: Linder 1943; Kwaśna *et al.* 2002.

NOTE. Colonies at first white, a few days later barium yellow (Ridgway 2005); sporophores arising from substrate in groups of 5–8, branching in the upper part, often divided into 3–4 branches, spirally twisted at tips; sporophores up to 4 mm high, 11–15 μm in diameter, regularly septate; fertile regions 75–160 μm long; sporocladia short-stipitate, the stipe 1-celled and 4–5 μm long, sporocladia 25–30 μm long × 7.5–12.0 μm wide, 6–7-celled, with terminal cell sterile, slightly curved; sporocladia in the lower parts of fertile regions mature

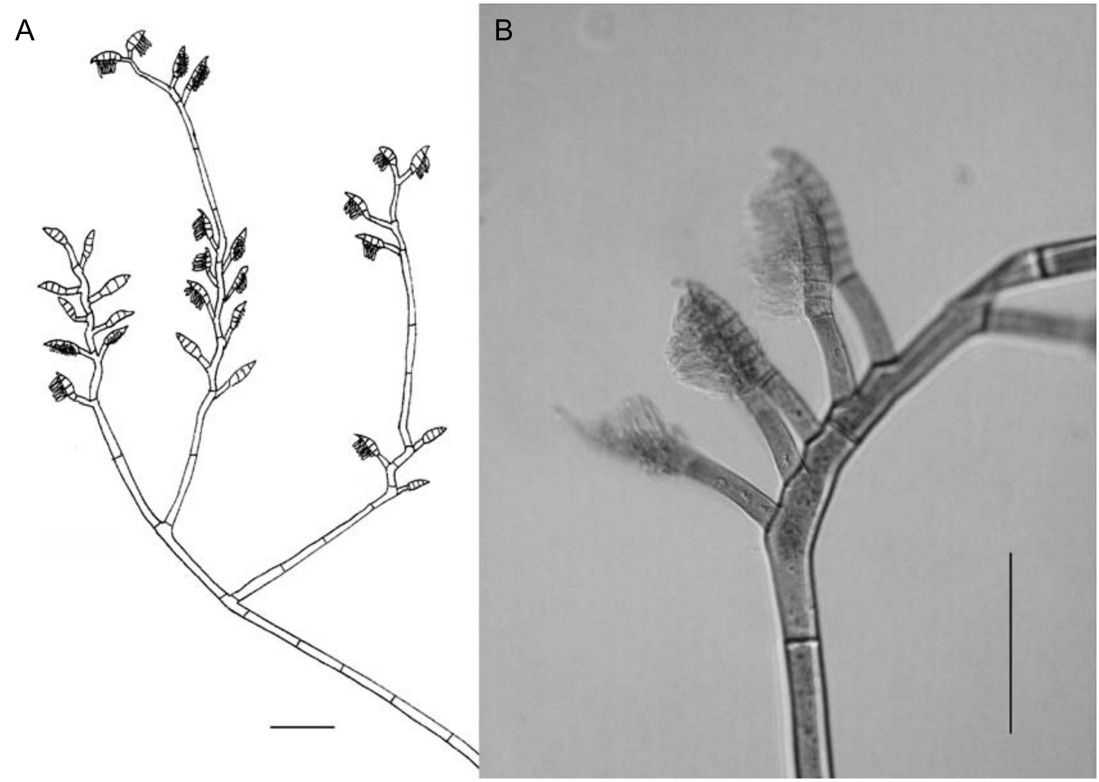


Fig. 2. *Coemansia* sp. 'interrupta-like'. A – sporophore bearing sporocladia, B – sporocladia. Scale bars = 50 μm.

earlier than those on the upper part, which often remain shorter, not divided into cells; pseudophialides long and thin, up to 3.8 μm long; conidia yellowish in mass, fusiform, 13–20 × 1.5–2.0 μm. Our specimen is similar to the *Coemansia spiralis* Eidam description given by Kwaśna *et al*. (2002) but differs substantially in type of ramification. Our specimen's sporophores emerge from the media in groups and are always furcate in the upper part, similarly to *Coemansia furcata* (Kurihara *et al*. 2000). The twisting of the fertile region of the sporophore as well as some microscopic characters distinguish it from the latter species.

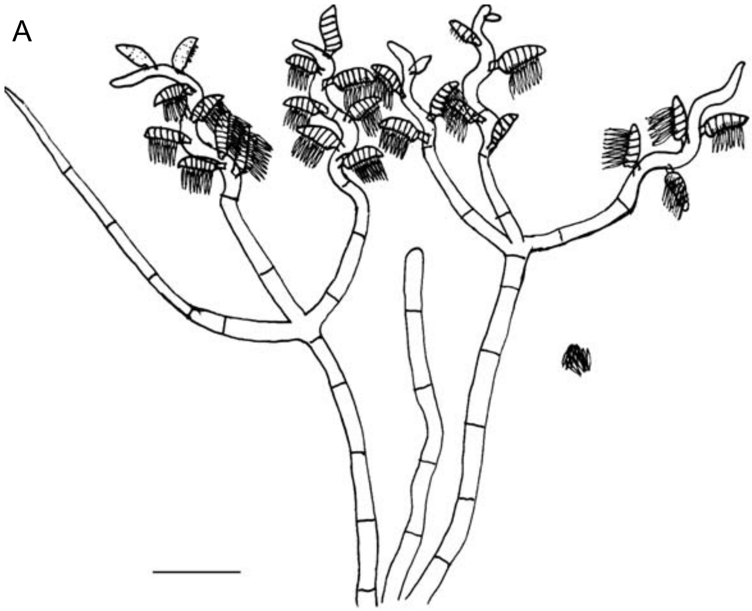
SPECIMEN EXAMINED: plot W8, peat soil, Biebrza National Park, burnt area.

Coemansia thaxteri Linder Fig. 4

REFERENCES: Linder 1943.

NOTE. Sporophores whitish, erect, simple or very rarely branched in the lower part, 1 cm or more long, 8–15 μm in diameter, regularly septate, cells quite long, some of them bearing one sporocladium on the upper part; sporocladial stipe elongated and composed of one or two cells which together measure 28–32 × 5–6 μm; sporocladia 5–8(–10) septate, 38–45 × 4–8 μm, the sterile terminal cell short or long, somewhat curved and tapering to a rounded apex; pseudophialides numerous at lower surface of sporocladial cells, ellipsoid, 3.3–4.5 × 2.5 μm; conidia narrow, fusiform, slightly rounded at apex, 15–18 × 2–3 μm. Our specimens differ from *C. thaxteri* (Linder 1943) in spore dimensions, (18.0–)21.0–23.5(–25.0) μm, but the other features accord with the original description so we identify it as *C. thaxteri*.

SPECIMENS EXAMINED: plots W8 and W2, peat soil, Biebrza National Park, burnt and unburnt areas.



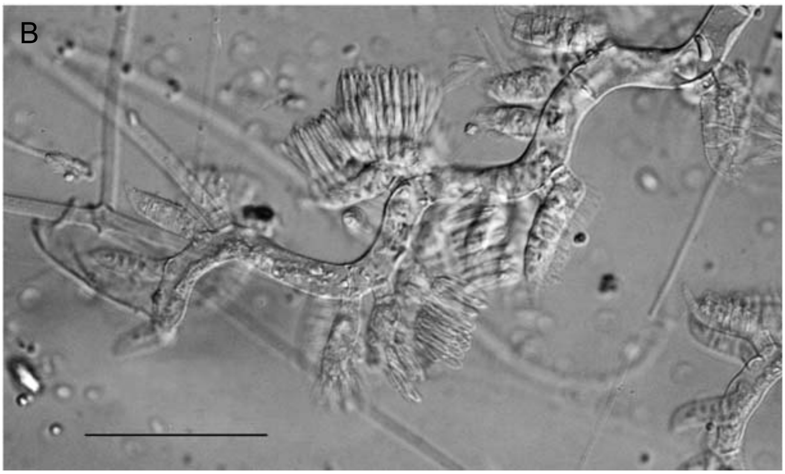


Fig. 3. *Coemansia* sp. 'spiralis-like'. A & B. – sporophore spirally twisted on the tips bearing sporocladia. Scale bars = 50 µm.

Mortierella ambigua B. S. Mehrotra Fig. 5

SYNONYMS: *Actinomortierella ambigua* (B. S. Mehrotra) Chalab.

REFERENCES: Mehrotra *et al.* 1963.

NOTE. Sporangiophore simple, erect, *ca* 1000 µm long, 37.5 µm wide at base, then tapering to 10.0–12.5 µm under subsporangial vesicle; the vesicle 18–20 µm in diameter; one primary and two short secondary sporangia on vesicle, each having collars; sporangiospores hyaline, smooth-walled, usually oblong or elliptic, 2.5 × 5 µm, sometimes reaching 5 × 7.5 µm. The sporangiophore is longer than in the original description (20–500 µm, Mehrotra *et al.* 1963), but this may be because the present description is based on specimens taken directly from the substrate.

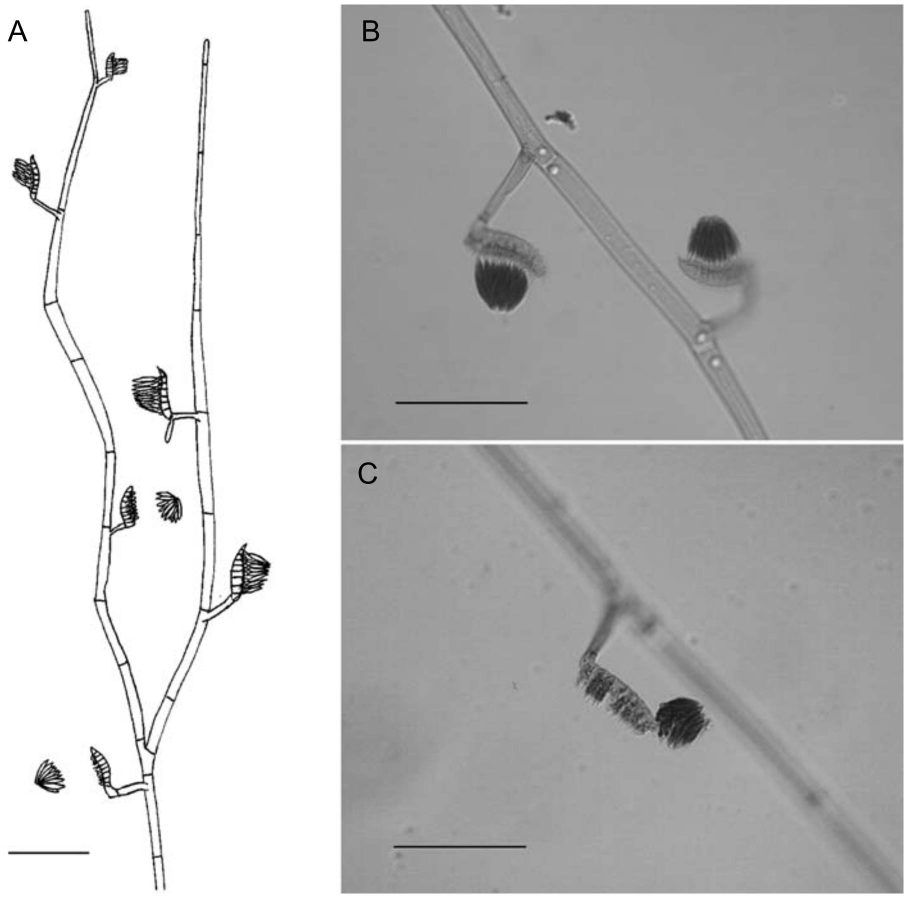


Fig. 4. *Coemansia thaxteri* Linder. A – sporophore bearing sporocladia, B – sporocladia, C – spores forming permanent mass of spores. Scale bars = 50 μm.

SPECIMENS EXAMINED: plots W2 and W7, Biebrza National Park, unburnt area, on unidentified plant debris.

Mortierella capitata Marchal Fig. 6

SYNONYMS: *Actinomortierella capitata* (Marchal) Chalab., *Actinomortierella vesiculosa* (B. S. Mehrotra, Baijal & B. R. Mehrotra) Chalab., *Carnoya capitata* (Marchal) Dewèvre, *Mortierella vesiculosa* B. S. Mehrotra, Baijal & B. R. Mehrotra

REFERENCES: Embree 1963; Mehrotra *et al.* 1963.

NOTE. Sporangiophore simple, erect, 570–700 μm long, tapering from 45–50 μm wide at the base to 10.0–12.5 μm wide under the vesicle; vesicle 20–25 μm in diameter, carrying one big central sporangium and a whorl of numerous short (up to 25 μm long), thin (2.5 μm) secondary branches arranged radially with smaller sporangia; all sporangia with deliquescent walls; sporangiospores spherical, 7.5–10.0(–12.5) μm in diameter, forming large (25.0–37.5 μm in diameter) and very persistent heads, leaving all together as sticky, mucilaginous masses. The sporangiophores of our specimen are larger than those from the original description, which are 200–400 μm long (Mehrotra *et al.* 1963). We identify this specimen as *M. capitata* because of sporangiospore shape and dimensions.

SPECIMEN EXAMINED: plot W7, Biebrza National Park, unburnt area, on unidentified plant debris.

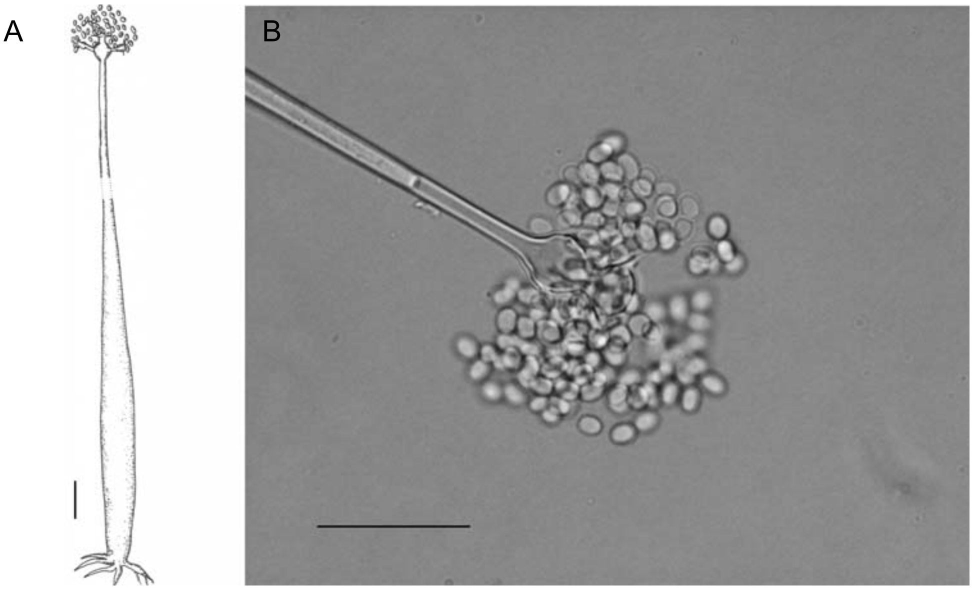


Fig. 5. *Mortierella ambigua* B. S. Mehrotra. A – sporangiophore, B – apical vesicle and sporangiospores. Scale bars: A = 50 µm, B = 30 µm.

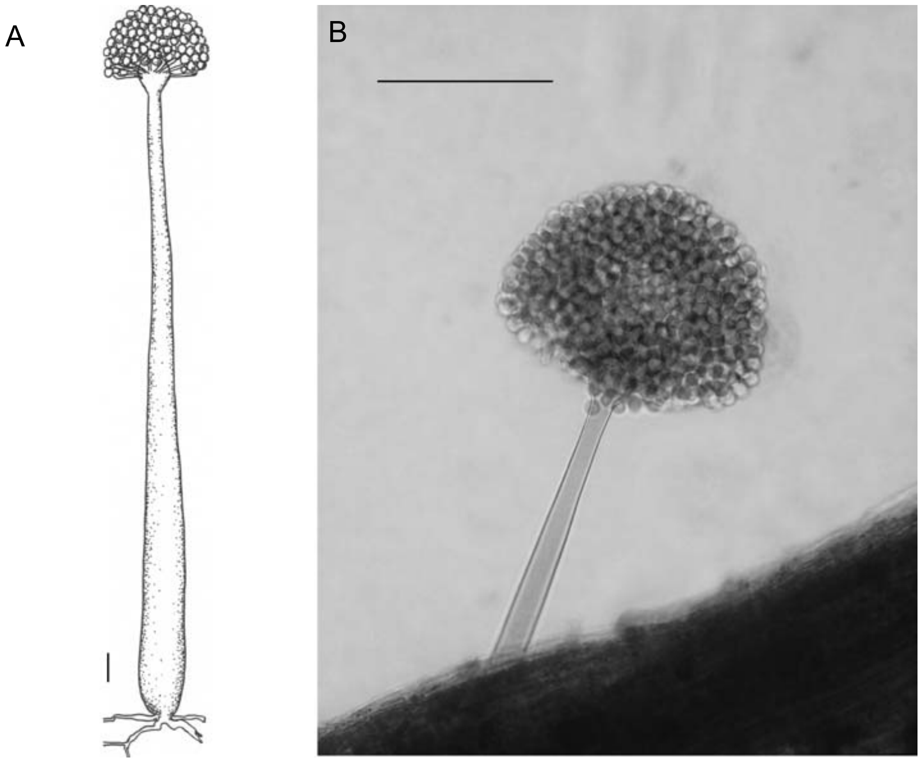


Fig. 6. *Mortierella capitata* Marchal. A & B – sporangiophore with head of spores. Scale bars: A = 50 µm, B = 100 µm.

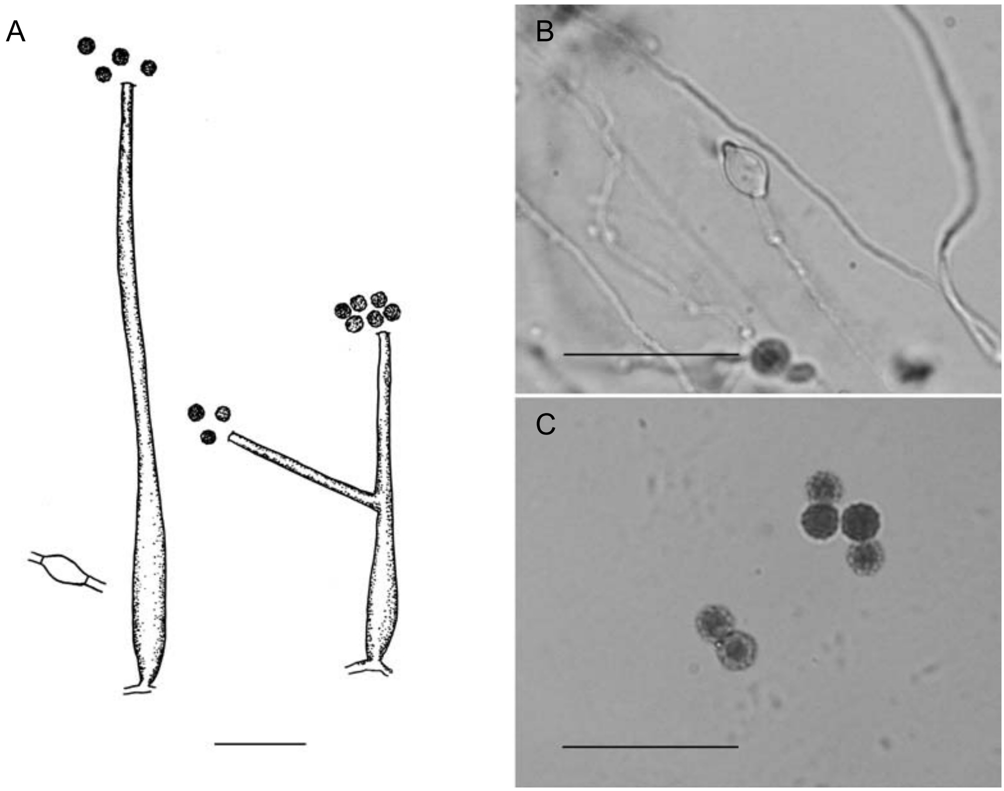


Fig. 7. *Mortierella verrucosa* Linnem. A – general view, B – lemon-shaped chlamydospore, C – spores. Scale bars: A = 50 µm, B & C = 30 µm.

Mortierella verrucosa Linnem. Fig. 7

REFERENCES: Linnemann 1953; Zycha *et al.* 1969.

NOTE. Colonies reaching 0.1–0.2 cm; sporangiophores simple or rarely branched, short (to 200 µm long), with widened base (up to 8 µm wide) and very thin apex (2 µm); branches formed in lower part or in the middle of the sporangiophore; collar and columella absent; sporangia (up to 25 µm in diameter) containing several spores; spores globose, 6–9 µm in diameter, slightly verrucose; chlamydospores lemon-shaped, yellowish, 10–15 µm long. The spores are smaller than in the original description by Linnemann (1953), making it very similar to *Mortierella ericetorum* Linnem. which has only simple sporangiophores according to the original description (Linneman 1953). The morphology of our specimens suggests that the two species may be synonyms.

SPECIMENS EXAMINED: plot W8, peat soil, burnt area; and plot W5, mineral soil, superficially burnt area, Biebrza National Park.

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