

Checklist of freshwater Ascomycetes in India

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A checklist of freshwater Ascomycetous fungi is presented based on the present studies in Maharashtra and published literature. Distribution of 93 species of freshwater Ascomycetes reported so far from various states of India is provided. These fungi have been recorded as saprophytes on naturally decaying submerged wood, leaves, wood test-blocks exposed in freshwater cooling tower, service timber packing of a freshwater cooling tower, and living leaves of *Typha angustata* Chaub. & Bory. The most frequently collected species of the genera are *Aniptodera*, *Annulatascus*, *Chaetomium*, *Jahnula*, *Leptosphaeria*, *Lophiostoma*, *Savoryella*, and *Zopfiella*. The most commonly encountered species are *Aniptodera chesapeakensis* Shearer & M.A. Mill., *Natantispora retorquens* (Shearer & J.L. Crane) J. Campb. et al., *Panorbis viscosus* (I. Schmidt) J. Campb. et al., *Savoryella aquatica* K.D. Hyde, and *Zopfiella latipes* (N. Lundq.) Malloch & Cain. The checklist includes detail of the location and substrata on which they encountered. This data will be useful in the compilation of fresh water fungal biodiversity of India.

Key words: Biodiversity, submerged wood, test-blocks

INTRODUCTION

Freshwater fungi are defined as "fungi that for the whole or part of their life cycle rely on freshwater" (Thomos, 1996). Freshwater Ascomycetes (FWA) are defined as Ascomycetes which have been recorded in freshwater habitats and which complete part, or the whole of their life cycle within freshwater environments (Shearer, 1993; Wong *et al.*, 1998). According to this definition, in addition to species of Ascomycetes that function in water, transient Ascomycetous fungi present in water and terrestrial Ascomycetous fungi that release spores that are dispersed in water are all regarded as FWA (Luo *et al.*, 2004), while Shearer *et al.* (2009) have considered FWA as only those species that occur

on submerged substrates and Ascomycetes on aerial parts of aquatic plants are considered terrestrial. Lignicolous FWA inhabit submerged woody material in lentic (e. g. lakes) and lotic (e. g. rivers) habitats (Wong *et al.*, 1998; Luo *et al.*, 2004).

Freshwater Ascomycetes comprise a diverse taxonomic assemblage of about 595 species (Raja and Shearer, 2011). These fungi are mostly saprobic on submerged woody and herbaceous debris and are important in aquatic food webs as decomposers and as a food source to invertebrate grazers. The freshwater Ascomycetes are one of the least studied groups of fungi. Although sporadic reports of Ascomycetous species that colonize aquatic macrophytes occur in the early Ascomycete systematic literature.

Late Prof. C.T. Ingold was the first to recognize that a distinctive freshwater Ascomycota might exist and published a series of papers about fungi on submerged substrates in the Lake District, England, UK (Ingold 1951, 1954, 1955; Ingold and Chapman, 1952). The early literature dealing with FA has been reviewed by Dudka (1965, 1985) and Shearer (1993). Since the 1990's interest in this group has grown and the number of species reported and/or described from freshwater habitats has increased by 370 (Shearer, 1993) to a total of 577 species (Shearer et al, 2009b). Goh and Hyde (1996), Wong et al. (1998), Shearer (2001), Tsui and Hyde (2003), Vijaykrishana et al. (2006), Cai et al. (2006), Shearer et al. (2007), and Raja et al. (2009) have presented more recent reviews.

Until the end of last decade, FWA have been studied mainly including Australia, Brunei, China, Hong Kong, Malaysia, USA, and UK. To India, Manoharachary and Rama Rao (1972) are the first to study FWA and described *Subbaromyces aquatica* as a new species from Andhra Pradesh. Manoharachary (1972) has isolated *Eleutherascus lectardii* (Nicot.) Arx from water and mud samples from Andhra Pradesh. Tilak and Kulkarni (1974) have described three FWA from Maharashtra. Natarajan and Udaiyan (1978) have reported *Emericella nidulans* on wood test blocks exposed in freshwater cooling towers. Udaiyan (1989) have reported 10 Ascomycetous species on wood test-blocks submerged in water-cooling tower dams from Tamil Nadu. Udaiyan and Hosogaudar (1991) have discovered nine taxa on test blocks submerged in water-cooling tower dams in Tamil Nadu. Udaiyan and Manian (1991a, b) and Udaiyan et al. (1993) have recorded 23 species of *Chaetomium* on wood test blocks submerged in a cooling tower water systems and treated service timber of water cooling tower systems. Agarwal et al. (1991) have described *Farlowiella indica* as a new species of FWA from Madhya Pradesh. Ramesh (2002) and Ramesh and Vijaykumar (2000, 2004, 2005, 2006) have listed some FWA on wood test-blocks submerged in various streams in Karnataka.

Borse and Pawara (2007) have reported two species of *Savoryella* from Maharashtra. Sridhar et al. (2010, 2011) and Sudheep and Sridhar (2011) have recorded some FWA from Karnataka. Patil (2012) has recorded species of *Zopfiella* from Maharashtra. Patil and Borse (2011, 2012a, b)

have reported some FWA from Maharashtra. Upadhyaya et al. (2012) have recorded some FWA from Narmada River in Madhya Pradesh. Borse et al. (2013a) reported two species of *Annulatascus* from Maharashtra. Many name changes in binomials have taken place in recent years and they have been appropriately amended to update. There is no publication that brings together all of these records on FWA from India. In this paper information on FWA of India is therefore collected and reviewed.

MATERIALS AND METHODS

Isolation by naturally submerged wood analysis

Monthly random collections of naturally submerged and partially decomposed woody debris (twigs or branches) were made from selected study sites along rivers and reservoirs in Maharashtra. The samples were returned to the laboratory keeping in plastic bags in the field and immediately examined with a dissecting microscope to locate fungal fruiting bodies. After the first observation, samples were incubated for three or more months on a moist paper towels in sterile plastic boxes at ambient temperature of 25°-30° C to stimulate fungal development. Incubated samples were examined on day 15 and then over three or more months under a dissecting microscope for ascocarps. The slides are made semi-permanent by using 'double cover glass method' (Volkman-Kohlmeyer and Kohlmeyer, 1996). The FWA encountered on the wood samples were isolated and identified.

Isolation by wood test blocks baiting technique

Test blocks of the teak and bamboo wood of the size 5x2x1 cm. were made. They were drilled centrally, sterilized by autoclaving at 12°C for 20 minutes and strung into ladders, with the blocks separated 2-3 cm. apart by knots on the nylon string. For each type of wood 9 replicate strings each carrying 10 blocks (90 teak + 90 bamboo) were prepared and later transferred to study sites to attach them to the stems or roots of trees standing near to the streams and dams, where they were submerged in water. Later on 3 strings (30 blocks) of each type of wood was removed every four months over a period of year.

These test blocks were returned to the laboratory

keeping in plastic bags in the field and immediately examined with a dissecting microscope to locate fungal fruiting bodies. After the first observation, they were incubated for few months on a moist paper towels in sterile plastic boxes at ambient temperature of 25° -30° C for three or more months to stimulate fungal development. Incubated test blocks were examined on day 10 and then over three or more months under a dissecting microscope for ascocarps. The slides were made semi-permanent as presented early.

RESULTS AND DISCUSSION

A list of 93 species of Freshwater Ascomycetes which have been identified to species level is pro-

vided alphabetically in Table 1. They belong to 42 genera of Ascomycota. The most frequent Ascomycetes are *Savoryella* (6 sp.), *Leptosphaeria* (4 sp.), *Zopfiella* (4 sp.), *Chaetomium* (25 sp.), *Aniptodera* (3 sp.), *Annulatascus* (3 sp.), *Lophiostoma* (3 sp.), *Pleospora* (2 sp.) and *Jahnula* (2 sp.). Some common FWA such as *Aniptodera chesapeakensis* Shearer & Miller, *Natantispora retorquens* (Shearer & J.L. Crane) J. Campb. et al., *Panorbis viscosus* (I. Schmidt) J. Campb. et al., *Savoryella aquatica* K.D. Hyde, and *Zopfiella latipes* (N. Lundq.) Malloch & Cain can be found at nearly every site investigated in Maharashtra. Most records of FWA were from states of Tamil Nadu (43 sp.), Karnataka (33 sp.), and Maharashtra (17 sp.), representing intensity of studies.

Table 1 : Freshwater Ascomycetes from India (Bold = New genera described, * = New species described, SW = Submerged wood, TB = Test Block, L = Leaf, W = Water, AP = Andhra Pradesh, MP = Madhya Pradesh, MS = Maharashtra, KA = Karnataka, TN = Tamil Nadu).

Species Name (1)	Sub- strate (2)	Location (3)	Reference (4)
<i>Anekabeeja lignicola</i> Udaiyan & V.S. Hosag.	TB	TN	Udaiyan & Hosagoudar (1991)
<i>Aniptodera chesapeakensis</i> Shearer & M.A. Miller	L,SW, TB	KA, MS, MP	Sudheep & Sridhar (2011), Patil & Borse (2012b), Ramesh (2002), Upadhyaya et al. (2012)
<i>Aniptodera lignatilis</i> K.D. Hyde	SW	KA	Sridhar et al. (2010)
<i>Aniptodera lignicola</i> K.D. Hyde, W.H. Ho & K.M. Tsui	SW	MS	Patil & Borse (2012b)
<i>Annulatascus hongkongensis</i> W.H. Ho, Ranghoo, K.D.Hyde & Hodgkiss	SW	MS	Borse et al. (2013)
<i>Annulatascus palmietensis</i> Goh, K.D. Hyde & Steinke	SW	MS	Borse et al. (2013)
<i>Annulatascus velatipora</i> K.D. Hyde	SW	KA	Sudheep & Sridhar (2011)
<i>Aqualignicola hyalina</i> Ranghoo, K.M. Tsui & K.D. Hyde	SW	KA	Sudheep & Sridhar (2011)
<i>Ascocacculus heterogattulata</i> (S.W. Wong, K.D. Hyde & E.B.G. Jones) J. Campb. et al.	SW	KA	Sridhar et al. (2011)
<i>Boerlagiomyces grandisporus</i> S.J. Stanley & K.D. Hyde	SW	KA	Sridhar et al. (2011)
<i>Caryospora putaminum</i> (Schwein) De Not.	SW	MS	Patil & Borse (2012a)
<i>Ceratocystis paradoxa</i> (Dade) C. Moreau	W	KA	Ramesh & Vijaykumar (2004)
<i>Chaetomium aureum</i> Chivers	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium biapiculatum</i> Lodha	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium brasiliense</i> Bat. & Pontual	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium brevopilium</i> L.M. Ames	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium britannicum</i> L.M. Ames	TB	TN	Udaiyan (1989)
<i>Chaetomium capreum</i> L.M. Ames	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium cochlioides</i> Palliser	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium convolutum</i> Chivers	L, SW	MP	Agarwal et al. (1991)
<i>Chaetomium elatum</i> Kunze	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium fibripilium</i> L.M. Ames	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium funiculosum</i> Cooke	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium gangligerum</i> L.M. Ames	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium globosum</i> Kunze ex Fries	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium gracile</i> Udagawa	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium incomptum</i> L.M. Ames	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium indicum</i> Corda	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium longicoleum</i> Krzemein & Badura	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium lunasporium</i> Udaiyan & V.S. Hosag.	TB	TN	Udaiyan & Hosagoudar (1991)
<i>Chaetomium medusarum</i> J.A. Mey. & Lanneau	TB	KA	Ramesh & Vijaykumar (2000)
<i>Chaetomium nigricolor</i> L.M. Ames	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium ochraceum</i> Tschudy	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium spirale</i> Zopf	TB	TN	Udaiyan & Manian (1991b)
<i>Chaetomium thermophilum</i> La Touche	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium turgidopilosum</i> L.M. Ames	TB	TN	Udaiyan et al. (1993)
<i>Chaetomium undulatum</i> Bainier	TB	TN	Udaiyan & Manian (1991b)
<i>Coniochaeta tetraspora</i> Cain	TB	TN	Udaiyan (1989)
<i>Corynascus sepedonium</i> (Emmons) Arx	TB	TN	Udaiyan (1989)

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(1)	(2)	(3)	(4)
<i>Didymosphaeria pittospora</i> Udaian & V.S. Hosag.	TB	TN	Udaian (1989)
<i>Eleutherascus lectardii</i> (Nicot.) Arx	W	AP	Manoharachary(1972)
<i>Emericella nidulans</i> (Eidam) Vuill.	TB	TN	Natarajan & Udaian (1978)
<i>Eutypa maura</i> (Fr. & Fr.) Fuckel	SW	KA	Sridhar et al. (2010)
<i>Eutypa flavovirens</i> (Pers.) Tul. & C. Tul.	SW	KA	Sudheep & Sridhar (2011)
<i>Farlowiella indica</i> G.P. Agarwal, Hasija, Agrawal, P & Pandey	SW	MP	Agarwal et al. (1991)
<i>Franticola tunitricuspis</i> K.D. Hyde	SW	KA	Ramesh & Vijaykumar (2005)
<i>Jahnula australiensis</i> K.D. Hyde	SW	KA	Ramesh & Vijaykumar (2005)
<i>Jahnula bipileata</i> Raja & Shearer	SW	KA	Sudheep & Sridhar (2011)
<i>Leptosphaeria aquatica</i> Tilak & R.L. Kulk.	L	MS	Tilak & Kulkarni (1974)
<i>Leptosphaeria dimidiata</i> Udaian & V.S. Hosag.	TB	TN	Udaian & Hosagoudar (1991)
<i>Leptosphaeria ginimia</i> K.M. Tsui, K.D. Hyde & Hodgkiss	SW	KA	Sridhar et al. (2010)
<i>Leptosphaeria peruviana</i> Speg.	SW	KA	Ramesh & Vijaykumar (2006)
<i>Lophiostoma bipolare</i> (K.D. Hyde) E.C.Y. Liew, Aptroot & K.D. Hyde	SW	KA	Sridhar et al. (2011)
<i>Lophiostoma frondisubmersum</i> (K.D. Hyde) E.C.Y. Liew, Aptroot & K.D. Hyde	SW	KA	Sridhar et al. (2010)
<i>Lophiostoma nucula</i> (Fr.) Ces. & De Not.	SW	KA	Sudheep & Sridhar (2011)
<i>Massarina australiensis</i> K.D. Hyde	SW	KA	Sridhar et al. (2010)
<i>Melanomma subdispersum</i> (P. Karst.) Berl. & Voglino	SW	KA	Sudheep & Sridhar (2011)
<i>Microascus lunasporus</i> P.M. Jones	TB	TN	Udaian (1989)
<i>Microthyrium ilicinum</i> De Not.	SW	KA	Sudheep & Sridhar (2011)
<i>Monascus ruber</i> Teigh.	TB	TN	Udaian & Manian (1991a)
<i>Mukhakesa lignicola</i> Udaian & V.S. Hosag.	TB	TN	Udaian & Hosagoudar (1991)
<i>Mycosphaerella aquatica</i> Udaian & V.S. Hosag.	TB	TN	Udaian (1989)
<i>Natantispora lotica</i> (Shearer) J. Campb. et al.	TB	KA	Ramesh (2002)
<i>Natantispora retorquens</i> (Shearer & J.L. Crane) J. Campb. et al.	SW	MS	Patil & Borse (2012a)
<i>Nectria byssicola</i> Berk. & Broome	SW	KA	Sridhar et al. (2010, 2011)
<i>Nectria den tifera</i> Samuels	TB	KA	Ramesh (2002)
<i>Neelakesa lignicola</i> Udaian & V.S. Hosag.	TB	TN	Udaian & Hosagoudar (1991)
<i>Niptera pilosa</i> (Crossl.) Boud.	TB	KA	Ramesh (2002)
<i>Ophiobolus munki</i> Tilak & R.L. Kulk.	L	MS	Tilak & Kulkarni (1974)
<i>Panorbis viscosus</i> (I. Schmidt) J. Campb. et al.	SW	MS	Patil & Borse (2012a)
<i>Petriella setifera</i> (Alf. Schmidt) Curzi	TB	TN	Udaian & Manian (1991b)
<i>Phaeonectriella lignicola</i> R.A. Eaton & E.B.G. Jones	TB	TN	Udaian (1989)
<i>Phaeosphaeria typharum</i> (Desm.) L. Holm	SW	KA	Sridhar et al. (2010)
<i>Phyllachora sylvatica</i> Sacc. & Speg.	SW	KA	Sridhar et al. (2010)
<i>Pleospora aurangabadensis</i> Tilak & R.L. Kulk.	L	MS	Tilak & Kulkarni (1974)
<i>Pleospora subramanianii</i> A. Pande	TB	TN	Udaian & Hosagoudar (1991)
<i>Pseudoeurotium multisporus</i> (Saito. & Mino.) Stol.	TB	KA	Ramesh & Vijaykumar (2000)
<i>Saccobolus beckii</i> Heimerl	TB	TN	Udaian (1989)
<i>Savoryella aquatica</i> K.D. Hyde	SW	MS	Borse & Pawara (2007)
<i>Savoryella fusiformis</i> W.H. Ho, K.D. Hyde & Hodgkiss	SW	MS	Patil & Borse (2011)
<i>Savoryella grandispora</i> K.D. Hyde	SW	MS	Patil & Borse (2011)
<i>Savoryella lignicola</i> E.B.G. Jones & R.A. Eaton	SW, TB	TN, KA, MS	Udaian (1989), Ramesh & Vijaykumar (2000), Borse & Pawara (2007)
<i>Savoryella limnetica</i> H.S. Chang & S.Y. Hsieh	SW	MS	Patil & Borse (2011)
<i>Savoryella verrucosa</i> Minoura & T. Muroi	SW	KA	Sridhar et al. (2011)
<i>Sporoniella minima</i> (Auersw.) Ahmed & Cain	TB	TN	Udaian & Manian (1991)
<i>Subbaromyces aquatica</i> Manohar. & P. Rama Rao	W	AP	Manoharachary & Ramarao (1974)

Contd. Table 1

(1)	(2)	(3)	(4)
<i>Thielavia hyalocarpa</i> Arx	TB	TN	Udaiyan (1989)
<i>Thielavia terricola</i> (J.C. Gilman & E.V. Abbott) C.W. Emmons	TB	TN	Udaiyan & Manian (1991)
<i>Torrentispora fibrosa</i> K.D. Hyde, W.H. Ho, E.B.G. Jones, K.M. Tsui & S.W. Wong	SW	KA	Sridhar et al. (2010)
<i>Zopfiella karachiensis</i> (S.L. Ahmed & Asad) Guarro	TB	TN	Udaiyan(1989)
<i>Zopfiella latipes</i> (N. Lundq.) Malloch & Cain	TB, SW	TN,KA, MS	Udaiyan(1989), Ramesh &
<i>Zopfiella lundqvistii</i> Shearer & J.L. Crane	TB	KA	Vijaykumar (2000), Patil (2012)
<i>Zopfiella submersa</i> Guarro, Al-Saadoon, Gene & Abdullah	SW	MS	Ramesh (2002) Patil (2012)

Studies on the FWA in India have yielded three new genera isolated from wood test-blocks submerged in water-cooling tower ponds and six new species, of which three were on wood test-blocks submerged in water-cooling tower ponds and two on living leaves of *Typha angustata* Chaub. & Bory. and one was isolated on maize grains baited in drainage water. Thirty nine species were reported from naturally submerged wood, 51 species on wood test-blocks exposed in water and service timber pickings of a water cooling towers, three species were encountered on both the natural submerged wood and wood test-blocks. Five species were found on leaves and three species isolated from water. Two species were found on both the submerged leaf and wood. The species: *Aniptodera chesapeakeensis* Shearer & M.A. Mill., *Natantisporea retorquens* (Shearer & J.L. Crane) J. Campb. et al., *Panorbis viscosus* (I. Schmidt) J. Campb. et al., *Savoryella lignicola* E.B.G. Jones & R.A. Eaton, *Zopfiella latipes* (N. Lundq.) Malloch & Cain were recorded from both marine and freshwater habitats in India (Borse, et al., 2012, 2013b). The species: *Frondicola tunitricuspis* K.D. Hyde and *Leptosphaeria peruviana* Spegazzini are substrate (host) / habitat (marine) specific ascomycetes and occurrence of these fungi on naturally submerged wood in freshwater habitats is unlikely (Kohlmeyer and Kohlmeyer, 1979, Jones et al., 2009).

As aquatic habitats are increasingly altered and degraded, it is imperative that the freshwater fungal species of the remaining high quality aquatic habitats be characterized and isolated. Such baseline information is essential to understand the role of fungi in aquatic habitats and how fungi could be used in the remediation of damaged aquatic

habitats. It is clear that those additional collections from worldwide, especially in tropical areas and along altitudinal gradients, are needed to fully characterize the biodiversity, geographical distribution pattern, systematics and evolution of freshwater Ascomycetes. In summary, we hope that the information presented herein will prompt future studies to document Freshwater Ascomycetes of India.

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