



## ***Xylaria* complex in the South Western India**

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### **Abstract**

Nine species of *Xylaria* (*X. escharoidea*, *X. filiformis*, *X. hypoxylon*, *X. longipes*, *X. multiplex*, *X. nigripes*, *X. obovata*, *X. polymorpha* and *X. symploci*) were recorded during an inventory of various habitats of the Western Ghats and west coast of India. *Xylaria escharoidea*, *X. hypoxylon* and *X. longipes* were common to the Western Ghats and west coast, while five (*X. filiformis*, *X. multiplex*, *X. obovata*, *X. polymorpha* and *X. symploci*) and one (*X. nigripes*) species were confined to the Western Ghats and west coast regions, respectively. *Xylaria longipes*, *X. multiplex*, *X. obovata* and *X. polymorpha* grew on dead logs/stubs, *X. escharoidea*, *X. nigripes* and *X. symploci* preferred to grow on soil/termite mound/soil embedded with wood, *X. hypoxylon* preferred to grow on pods/kernels/twigs/humus/wood pieces and *X. filiformis* exclusively grew on leaves. *Xylaria filiformis* and *X. multiplex* recorded for the first time from the Western Ghats. Based on the occurrence on different substrates, a dichotomous key has been given for identification of nine species recorded in this survey. Including this survey, a total of 24 species of *Xylaria* has been reported from the Western Ghats and west coast regions of Maharashtra, Karnataka, Kerala and Tamil Nadu.

**Key words** – Agroforestry – termite mound – Western Ghats – wood

### **Introduction**

Although conservative estimate of fungal species worldwide ranges from 1.5 to 5.1 million, currently accepted number of fungi ranges between 0.5 and 3 million (Hawksworth 1991, 2012, Blackwell 2011). According to *The Dictionary of the Fungi* and *Index of Fungi*, from 1943 and 2008, on an average 950 species in 73 genera of fungi have been introduced (Dai et al. 2015). The number of ascomycetes as a percentage of known fungi has almost doubled during this period. Although the Western Ghats constitutes one of the hotspots of biodiversity by virtue of its geographic location, ecological niches and endemism, mycological explorations are not seriously undertaken.

The saprobic lignin degraders belong to the ascomyceteous genus *Xylaria* Hill ex Schrank is cosmopolitan and characterized by more or less carbonaceous sessile or stipitate erect stromata with simple or branched cylindrical to clavate or globoid or irregular fertile parts (Roger 1979, Trierveiler-Pereira et al. 2009). About 780 epithets of *Xylaria* have been documented in the Index Fungorum (2015). Many of them are abundant in tropics and subtropics (Kirk et al. 2008, Trierveiler-Pereira et al. 2009, Ma et al. 2013a). The diameter of stromata varies between 0.5 mm (tiny: *Xylaria filiformis*) (Rogers & Samuels 1986) and 5.5 cm (bulb-like: *Xylaria acuminatilongissima*) (Latha et al. 2015). *Xylaria* grow on a variety of substrates especially on

decorticated wood, dung and nests of termites/ants (Rogers 2000, Duong et al. 2004, Okane et al. 2008, Hsieh et al. 2010). They are also endophytes in live tissues of a wide host range including broad-leaved trees, palms, orchids, bromeliads, aroids and liverworts (Bayman et al. 1998, Davis et al. 2003, Okane et al. 2008, Oliveira et al. 2011; Linnakoski et al. 2012, Rajulu et al. 2013). *Xylaria* species are known for their medicinal value and produce a variety of bioactive compounds (e.g. alkaloids, antifungal metabolites, cytochalasins, cell-degrading enzymes, exopolysaccharides, xylaramide, xylarin and xyloketals) (Dagne et al. 1994, Schneider et al. 1995, 1996, Boonphong et al. 2001, Lin et al. 2001, Ramesh et al. 2012a, Ma et al. 2013b, Rajulu et al. 2013, Latha et al., 2015). Investigations in the Western Ghat region including this study (in the States of Maharashtra, Karnataka, Kerala and Tamil Nadu) revealed occurrence of 24 *Xylaria* species with a highest, 17 species in Maharashtra followed by 10 species in Karnataka, 7 species in Kerala and 1 species in Tamil Nadu (Table 1). The current study reports occurrence of nine species of *Xylaria* based on a recent survey on various substrates and locations of the Western Ghats and west coast of India.

## Materials & Methods

During macrofungal survey in the Kodagu region of Western Ghats (forests reserve, national parks, sacred groves, agroforests and Shola forests) and the Konaje village of west coast (scrub jungles, *Acacia* forests and arboretum), nine *Xylaria* spp. were obtained growing mainly on lignocellulosic materials. General characteristics were examined based on teleomorphic stromata followed by detailed microscopic examination of perithecia, asci and ascospores with light microscope (Olympus CX41RF) using diagnostic keys (Rogers & Samules 1986, Lee et al. 2002, Ju & Hsieh 2007, Rogers et al. 2008, Kshirsagar et al. 2009, Trierveiler-Pereira et al. 2009). Photographs of each species were taken using digital camera (Nikon, D40 USA). The *Xylaria* spp. collected were fixed in water-ethanol-formaldehyde and deposited in mycological herbarium, Department of Biosciences, Mangalore University, Mangalagangothri, Mangalore (NCK # 046–059: *Xylaria escharoidea*, *X. filiformis*, *X. hypoxylon*, *X. longipes*, *X. multiplex*, *X. nigripes*, *X. obovata*, *X. polymorpha* and *X. symploci*).

## Results

Nine species of *Xylaria* collected from the Western Ghats and west coast of India were designated based on detailed macro- and micro-morphological characteristics and literature. A brief description of each species recovered in the present study is given along with their substrate preference and distribution with a dichotomous key. General characteristic features of nine species of *Xylaria* found in this study have been compared in Table 2.

***Xylaria escharoidea* (Berk.) Sacc. Syll. Fung. (Abellini) 1: 316 (1882) (Fig 1A, B)**

Solitary or in small group, annual, particulous, rare, odor and taste not distinctive and inedible.

Stromata at first dull-black, smooth, whip-like, long with smoky-white conidial deposits, on maturity become black with elongated, broad, cylindrical to fusoid, smooth to warty, longitudinally wrinkled, round apex to obtuse fertile head and tapering below into blackish-brown to dull-brown, short to long sterile stem (epigeal), deeply embedded in soil by small to long rooting base, occasionally branched in the rooting base with two or more medium to long, black, cylindrical-fusoid fertile stromata, flesh white and hard, ostiole papillate and single stromata measures 7.8–15.7 cm tall × 0.3–0.5 cm thick.

Perithecia black, sub-spherical, fully embedded in fertile head, 0.1–0.2 mm diam., arranged in a single dense layer just below the surface. *Asci* cylindrical, long stipitate, 8-spored and measures 40–52 × 3.4–4.6 μm. *Ascospores* brown, inequilaterally ellipsoidal, aseptate, uniseriate and measures 3.7–5.2 × 2.5–3 μm.

Substrate and distribution – Found on inactive termite mounds in Shola forest, Jodupala, Kodagu, Western Ghats (July 04, 2012; N.C. Karun: NCK # 046); Arboretum, Konaje, west coast, Mangalore (August 05, 2014; N.C. Karun: NCK # 047).

**Table 1** Reports on *Xylaria* in the Western Ghats and west coast of India.

Taxon	Substrate	Locality (State)	Reference
<i>Xylaria acuminatilongissima</i> Y.M. Ju & H.M. Hsieh	Abandoned termite nests	Pattambi (Kerala)	Latha et al. (2015)
<i>Xylaria anisopleura</i> (Mont.) Fr.	?	Mulashi forest (Maharashtra)	Kshirsagar et al. (2009)
<i>Xylaria beccari</i> Pess.	?	Mulashi forest (Maharashtra)	Kshirsagar et al. (2009)
<i>Xylaria brevipes</i> Starbäk	?	Mulashi forest (Maharashtra)	Kshirsagar et al. (2009)
<i>Xylaria carpophila</i> (Pers.) Fr.	?	Semi-evergreen & moist-deciduous forests (Karnataka)	Swapna et al. (2008)
<i>Xylaria curta</i> Fr.	Soil & bark	Courtallum Hills (Tamil Nadu)	Ramesh et al. (2012b)
<i>Xylaria escharoidea</i> (Berk.) Sacc. (Fig. 1A, B)	Abandoned termite nests	Chandhakkunnu, Nilambur (Kerala) Shola forest, Jodupala (Karnataka)	Mohan (2011) Karun & Sridhar (Present study)
<i>Xylaria feejeensis</i> (Berk.) Fr.	?	Arboretum, Konaje (Karnataka) Mulashi forest (Maharashtra)	(Present study) Kshirsagar et al. (2009)
* <i>Xylaria filiformis</i> (Alb. & Schwein.) Fr. (Fig. 1C, D)	Leaf litter ( <i>Euodia lunuankenda</i> )	Shola forest, Sampaje (Karnataka)	Karun & Sridhar (Present study)
<i>Xylaria gigantea</i> Fr.	Leaf litter	Satara & Kas (Maharashtra)	Ranadive & Jagtap (2013)
<i>Xylaria grammica</i> (Mont.) Mont.	Soil	Kas (Maharashtra)	Patil et al. (2012)
<i>Xylaria hypoxylon</i> (L.) Grev. (Fig. 1E, F)	?	Mulashi forest (Maharashtra)	Kshirsagar et al. (2009)
	On wood ( <i>Xylia xylocarpa</i> )	Peechi & Vazhani (Kerala)	Florence & Yesodharan (2000)
	Decaying pods, seeds, rotting branches, wood, logs & forest litter	Chandhakkunnu & Iringole Kavu (Kerala)	Mohan (2011)
	Bark/Wood	Bhadra Wildlife Sanctuary (Karnataka)	Thirumalesh et al. (2014)
	Decaying twigs ( <i>Acacia auriculiformis</i> )	Konaje (Karnataka)	Karun & Sridhar (2014)
	Leaf litter, twig & dead seeds ( <i>Cassine glauca</i> )	Coffee agroforest, Virajpet (Karnataka)	Karun & Sridhar (Present study)
	Twig litter & dead pods of <i>Cassia fistula</i>	<i>Acacia</i> forest, Konaje (Karnataka)	
<i>Xylaria juruensis</i> Henn.	?	Mulashi forest (Maharashtra)	Kshirsagar et al. (2009)
<i>Xylaria longipes</i> Nitschke (Fig. 3A–D)	Decaying wood & logs	Chandhakkunnu, Iringole Kavu & Vadanamkurissi (Kerala)	Mohan (2011)
	Rotting logs/stumps ( <i>Acrocarpus fraxinifolius</i> , <i>A. hirsutus</i> , <i>Erythrina subumbrans</i> , <i>Memecylon umbellatum</i> & <i>Syzygium cumini</i> )	Sacred grove, Maggula; forest reserve Sampaje; agroforest, Makutta, V'Badaga & B'Shettigeri (Karnataka)	Karun et al. (2014)

**Table 1 continued**

Taxon	Substrate	Locality (State)	Reference
Dead stub ( <i>Cassineglauca</i> , <i>Acrocarpus</i> <i>fraxinifolius</i> , <i>Artocarpus</i> <i>heterophyllus</i> & <i>A.</i> <i>hirsutus</i> <i>Xylaria longipes</i> Nitschke (Fig. 3A–D)	Coffee agroforest, Virajpet; sacred grove, Kadnur; forest reserve Makutta (Karnataka)	Karun & Sridhar (Present study)	Dead stub ( <i>Cassineglauca</i> , <i>Acrocarpus</i> <i>fraxinifolius</i> , <i>Artocarpus</i> <i>heterophyllus</i> & <i>A.</i> <i>hirsutus</i>
	Dead stub ( <i>Acacia</i> <i>auriculiformis</i> , <i>Mangifera indica</i> & <i>Syzygium</i> <i>cumini</i> )	Acacia forest, Konaje (Karnataka)	
	Decaying log Abandoned termite nests	Makutta forest reserve (Karnataka) Sidhanpocket & Chandhakkunnu (Kerala)	Karun & Sridhar (Present study) Mohanan (2011)
* <i>Xylaria multiplex</i> (Kunze) Fr. (Fig. 3E, F)	Wood embedded in soil & ectomycorrhizal	Konaje (Karnataka)	Karun & Sridhar (2014)
<i>Xylaria nigripes</i> (Klotzsch) Cooke (Fig. 4A–C)	Abandoned termite nests ?	Garden, Konaje (Karnataka)	Karun & Sridhar (Present study)
	Decaying logs ( <i>Terminaliabellir</i> <i>ica</i> )	Mulashi forest (Maharashtra) Sacred grove, Kottoli (Karnataka)	Kshirsagar et al. (2009) Karun & Sridhar (Present study)
<i>Xylaria obovata</i> (Berk.) Berk. (Fig. 4D, E)	? Decaying wood & logs	Mulashi forest (Maharashtra) Ammayambalam (Kerala)	Kshirsagar et al. (2009) Mohanan (2011)
<i>Xylaria oligotoma</i> Sacc. & Paol.	Wood	Patgaon, Maharashtra	Patil et al. (2012)
<i>Xylaria poitei</i> (Lév.) Fr.	On wood of <i>Bamboo</i> & seeds ( <i>Xyliaxylocarpa</i> ) ?	Peechi, Vallikkayam & Kuthirn (Kerala)	Florence & Yesodharan (2000)
<i>Xylaria polymorpha</i> (Pers.) Grev. (Fig. 4F–I)	Decaying wood & logs Bark/Wood	Moist-deciduous forest (Karnataka) Iringole Kavu & Ammayambalam (Kerala)	Swapna et al. (2008) Mohanan (2011)
	Decaying logs ( <i>Terminaliabellir</i> <i>ica</i> & <i>Toona</i> <i>ciliata</i> )	Bhadra Wildlife Sanctuary (Karnataka)	Thirumalesh et al. (2014)
	Decaying log ( <i>Ficus recemosa</i> )	Shola forest, Sampaje; Coffee agroforest, B'Shettigeri (Karnataka)	Karun & Sridhar (Present study)
	Decaying log ( <i>Ficus recemosa</i> )	Pune (Maharashtra)	Hsieh et al. (2010)
	? ?	Mulashi forest (Maharashtra) Mulashi forest (Maharashtra)	Kshirsagar et al. (2009) Kshirsagar et al. (2009)
<i>Xylaria regalis</i> Cooke <i>Xylaria schweinitzii</i> Berk. & M.A. Curtis	Roots ( <i>Symplocos</i> <i>recemosa</i> )	Anshi National Park (Karnataka)	Pande et al. (2005)
<i>Xylaria scruposa</i> (Fr.) Fr.	On soil around tree trunk	Kaikatty & Thirunelly (Kerala)	Mohanan (2011)
<i>Xylaria symploci</i> Pande, Waingankar, Punekar & Ranadive (Fig. 4J)	On soil in basin of standing dead tree	Makutta forest reserve (Karnataka)	Karun & Sridhar (Present study)

\*, first report to the Western Ghats of India.

?, not defined.

*Xylaria filiformis* (Alb. & Schwein.) Fr. Summa veg. Scad., Section Post. (Stockholm): 382 (1849) (Fig 1C, D)

Gregarious, annual, humicolous, rare, odor and taste not distinctive and inedible.

Stromata at first blackish-brown, delicate, thread-like, flexible, smooth with whitish conidial deposits, on maturity becoming blackish-brown and with fertile grooved collars slightly bulged at junctions towards apex (1–3 bulges). Rest of the sterile part hairy to slender, flexible, smooth, downy, attached firmly on veins of degrading leaves, flesh white and fibrous, ostiole papillate and single stromata measures 4–12 cm tall × 0.5–1 mm thick.

Perithecia black, sub-spherical, fully embedded in fertile grooved collar,  $\geq 0.1$  mm diam. and arranged in single dense layer just below the surface. Asci cylindrical, long stipitate, 8-spored and measures  $150\text{--}170 \times 6\text{--}8.5$   $\mu\text{m}$ . Ascospores brown, ellipsoid-inequilateral, aseptate, uniseriate and measures  $13\text{--}18 \times 5\text{--}8$   $\mu\text{m}$ .

Substrate and distribution – On leaf debris and degrading leaves of *Euodia lunuankenda* in Shola forest, Sampaje, Western Ghats (August 03, 2012; N.C. Karun: NCK # 048). This is the first record for the Western Ghats of India.

**Table 2** Comparison of characteristic features of nine species of *Xylaria*.

Taxon	Substrate	Shape and color of stromata		Color of conidial deposit on immature stromata	Mature fruit body	
		Immature	Mature		Surface	Overall size
<i>X. escharoidea</i> (Fig. 1A, B)	Particolous (termite mound)	Whip-like (dull-black)	Cylindric to fusoid (black)	Smoky-white	Smooth to warty become longitudinally wrinkled	Medium to large
<i>X. filiformis</i> (Fig. 1C, D)	Humicolous	Thread-like (blackish-brown)	Hairy to slender (blackish-brown)	Whitish	Smooth sterile part and grooved fertile part	Small
<i>X. hypoxylon</i> (Fig. 1E, F)	Lignicolous/humicolous	Whip-like (black)	Antler (black)	Greyish-white/ash-white	Smooth	Medium
<i>X. longipes</i> Nitschke (Fig. 3A–D)	Lignicolous	Clavate (black)	Sub-cylindric to clavate (black)	Smoky-white/greyish-white	Smooth to finely warty become longitudinally wrinkled	Medium
<i>X. multiplex</i> (Fig. 3E, F)	Lignicolous	Clavate (black)	Cylindric (blackish-brown)	Smoky-white	Undulated grooves and ridges	Small
<i>X. nigripes</i> (Fig. 4A–C)	Particolous (termite mound)	Whip-like (dull-black)	Cylindric (black)	Pinkish-grey	Smooth to warty	Medium
<i>X. obovata</i> (Fig. 4D, E)	Lignicolous	Clavate to sub-spherical (reddish-brown/purple-brown)	Sub-globose (blackish-brown)	Ash-grey	Warty	Small to medium
<i>X. polymorpha</i> (Fig. 4F–I)	Lignicolous	Irregular to clavate (greyish-black)	Cylindric/irregular/clavate (black)	Smoky-white/ash-grey	Warty become finely wrinkled	Medium to large
<i>X. symploci</i> (Fig. 4J)	Particolous	Cylindric to clavate (black)	Cylindric to clavate (black)	Yellowish-green	Finely warty become wrinkled	Large

*Xylaria hypoxylon* (L.) Grev. Fl. Edin.: 355 (1824)

(Fig 1E, F)

Occur in small to large groups, annual, lignicolous/humicolous, common, odor and taste not distinctive and inedible.

Stromata at first blackish, velvety to smooth, whip-like to sparsely branched with greyish-white to ash-white conidial deposits, with age becoming black, smooth, flexible, irregularly antler-shaped and fertile with pointed apices and merging below into blackish-brown to greyish-brown, short to long sterile stem (epigeal), and embedded in humus/wood /pods/seeds/kernels by means of

small to long rooting base, flesh white, smooth and flexible, ostiole papillate and stromata measures 3–9 cm tall (variable in diam.).

Perithecia black, sub-spherical, fully embedded in antlers, 0.3–0.4 mm diam. and arranged in a single dense layer just below the surface. Asci cylindrical, long, stipitate, 8-spored and measures  $95\text{--}125 \times 5.2\text{--}5.8 \mu\text{m}$  (Fig. 2A). Ascospores blackish-brown, ellipsoid-inequilateral, aseptate, uniseriate and measures  $10.8\text{--}14.6 \times 5\text{--}6 \mu\text{m}$  (Fig. 2B).

Substrate and distribution – On leaf debris and degrading seed/kernels of *Cassine glauca* in coffee agroforest, Virajpet, Kodagu, Western Ghats (August 05, 2012; N.C. Karun: NCK # 049); on leaf/twig debris of *Acacia auriculiformis*, on degrading pods/twigs of *Cassia fistula* in *Acacia* forest, Konaje, west coast, Mangalore (August 09, 2012; N.C. Karun: NCK # 050).



**Fig 1** – *Xylaria escharoidea* showing immature stages of stromata on termite mound (A) and different maturity stages with smoky white conidial deposit (B); *Xylaria filiformis* grown on leaf litter (C) and petioles (D) showing characteristic fertile collars on stromata (arrows); *Xylaria hypoxylon* grown on decaying pods of *Cassia fistula* (E) showing characteristic antler-shaped stromata (F) (Scale bar, 1 cm).

*Xylaria longipes* Nitschke Pyrenomyc. Germ. 1: 14 (1867)

(Fig 3A–D)

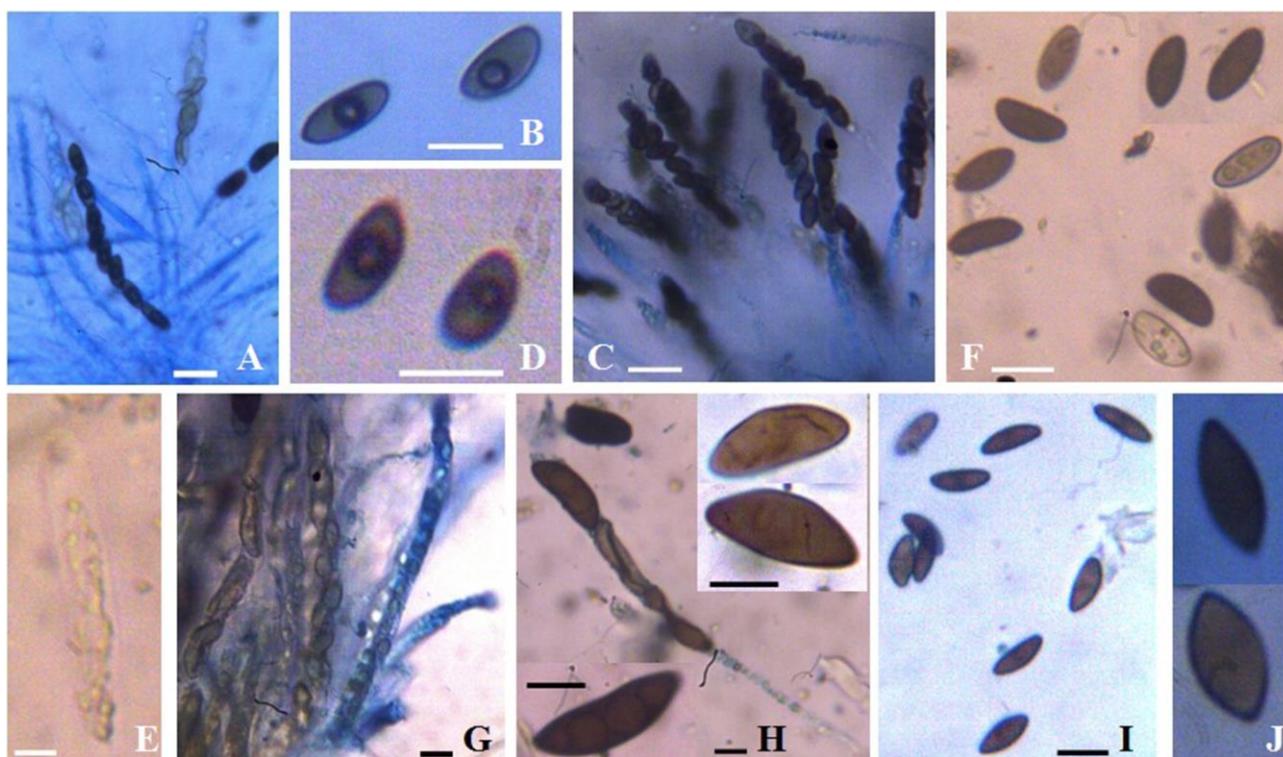
Arising in tufts/groups, annual, lignicolous, frequent, taste and odor not distinctive and inedible.

Stromata at first blackish, smooth, clavate with smoky-white to greyish-white conidial deposits, on age becoming black with sub-cylindric to clavate, broad, smooth to finely warty, longitudinally wrinkled, apex round fertile head and narrowing below into a brownish black, short

to long sterile stem firmly attached to the wood by means of small to long rooting base, flesh white and hard, ostiole papillate and stromata measures 2.8–6.6 cm tall × 0.4–0.8 cm thick.

Perithecia black, sub-spherical, fully embedded in fertile head, 0.5–1 mm diam. and arranged in single dense layer just below the surface. Asci cylindrical, long, stipitate, 8-spored and measures 147–163 × 6–8 μm (Fig. 2C). *Ascospores* dark brown, ellipsoid-inequilateral, aseptate, uniseriate and measures 12.5–14.5 × 5.5–6.0 μm (Fig. 2D).

Substrate and distribution – On dead stub (*Cassine glauca*, *Acrocarpus fraxinifolius*, *Artocarpus heterophyllus* and *A. hirsutus*), coffee agroforest, Virajpet (May 01, 2012; N.C. Karun: NCK # 051).; sacred grove, Kadnur; forest reserve Makutta, Western Ghats, Karnataka; on dead stub (*Acacia auriculiformis*, *Mangifera indica* and *Syzygium cumini*) in *Acacia* forest, Konaje, west coast, Karnataka (June 01, 2012; N.C. Karun: NCK # 052).; rotting logs and stumps (*Acrocarpus fraxinifolius*, *A. hirsutus*, *Erythrina subumbrans*, *Memecylonum bellatum* and *Syzygium cumini*) in sacred grove, Maggula (June 02, 2012; N.C. Karun: NCK # 053).



**Fig 2** – Immature/mature asci (A) and ascospores (B) of *Xylaria hypoxylon*; Immature/mature asci (C) and ascospores (D) of *X. longipes*; Immature ascus (E) and ascospores (F) of *X. multiplex*; Immature/mature asci (G, H) and ascospores (H) of *X. obovatum*; Ascospores of *X. polymorpha* (I); Ascospores of *X. symplosi* (J) (Scale bar, 10 μm).

*Xylaria multiplex* (Kunze) Fr. Nova Acta R. Soc. Scient. Upsal., Ser. 3, 1 (1): 127 (1851) (1855)

(Fig. 3E, F)

Caespitose or in tufts, annual, lignicolous, infrequent, taste and odor not distinctive and inedible.

Stromata at first blackish, smooth, clavate, with smoky-white conidial deposits, on age becoming blackish-brown with elongated, cylindric, undulated (grooved and ridged), apex round-acutefertile head and narrowing below into a brownish-black, short sterile stem firmly attached to the wood by means of small to long rooting base, flesh white and brittle, ostiole papillate and stromata measures 3.3–5.1 cm tall × 0.1–0.2 cm thick.

Perithecia black, sub-spherical, elevated, fully embedded in fertile head, 0.3–0.4 mm diam. and arranged in a single dense layer just below the surface. Asci cylindrical, long, stipitate, 8-

spored and measures  $100\text{--}126 \times 5.8\text{--}6.3 \mu\text{m}$  (immature ascus, Fig. 2E). *Ascospores* purple black, ellipsoid-inequilateral, aseptate, uniseriate and measures  $8.9\text{--}10.8 \times 3.9\text{--}4.7 \mu\text{m}$  (Fig. 2F).

Substrate and distribution – On dead and degrading log in Makutta forest reserve, Virajpet, Western Ghats, Karnataka (September 01, 2012; N.C. Karun: NCK # 054). This is the first record for the Western Ghats of India.



**Fig 3** – *Xylaria longipes* grown on decaying wood showing immature (A) and partially mature (B) stromata with greyish-white conidial deposits; mature stromata (C), fully matured and spent stromata (D) on partially buried wood; *Xylaria multiplex* grown on degrading log exhibiting ridges and grooves on the stromatal surface (E, F) (Scale bar, 1 cm).

*Xylaria nigripes* (Klotzsch) Cooke Grevillea 11 (59): 89 (1883) (Fig 4A–C)

Caespitose or typically in clusters, annual, particolous, infrequent to rare, odor and taste not distinctive and inedible.

Stromata at first dull black, smooth, whip-like, short to long with pinkish-grey conidial deposits, on age becoming greyish-brown and then blackish with elongated, broad, cylindrical, smooth to warty, apex round to acute fertile head and narrowing/tapering below into a blackish, short to long, sterile stem (epigeal) deeply embedded in soil by means of small to long rooting base, occasionally branched in the rooting base with two or more, black, cylindric fertile, flesh white, hard and brittle. ostiole papillate and single stromata measures  $4.5\text{--}8.2 \text{ cm tall} \times 0.3\text{--}0.5 \text{ cm thick}$ .

Perithecia black, sub-spherical, fully embedded in fertile head,  $0.1\text{--}0.3 \text{ mm diam.}$ , and arranged in single dense layer just below the surface. *Asci* cylindrical, long, stipitate, 8-spored and measures  $62\text{--}78 \times 3.5\text{--}4 \mu\text{m}$ . *Ascospores* brown, ellipsoid-inequilateral, aseptate, uniseriate and measures  $5.3\text{--}7.9 \times 2.6\text{--}3.3 \mu\text{m}$ .

Substrate and distribution – Found embedded in soil and ectomycorrhizal in *Bougainvillea spectabilis*, Konaje, west coast, Karnataka (July 10, 2014; Karun: NCK # 055); found on inactive termite mounds in gardens of Konaje, west coast, Karnataka (August 15, 2012; N.C. Karun: NCK # 056).



**Fig 4** – *Xylaria nigripes* showing immature stages of stromata established on termite mound with pinkish-grey conidial deposit (A), intermediate stage of stromata (B) and different stages of developing stromata (C); *Xylaria obovata* grown on rotting log showing oozing ascospores on the surface of stromata (D) and fully matured brownish-black stromata (E); *Xylaria polymorpha* grown on bark/wood of standing dead tree trunk (F, G) with various shapes and sizes of stromata (H, I); *Xylaria symploci* showing partially matured stromata with pale yellowish-green conidial deposits on the surface (J) (Scale bar, 1 cm).

*Xylaria obovata* (Berk.) Berk. Nova Acta R. Soc. Scient. Upsal., Ser. 3, 1 (1): 127 (1851)

(Fig 4D, E)

Gregarious in rotting logs, annual, lignicolous, rare, taste and odor not distinctive and inedible.

Stromata at first reddish-brown/purple-brown, smooth, clavate-subspherical with ash-grey conidial deposits, on age becoming brownish-black and then blackish-brown with sub-globose, warty, strictly apex round fertile head, narrowing below into a black, short and stout sterile stem firmly attached to the wood by means of small to long rooting base, flesh white and hard, ostiole papillate and stromata measures 1.8–2.9 cm tall × 0.9–2.4 cm thick.

Perithecia black, sub-spherical, innate, fully embedded in fertile head, 0.5–1 mm diam. and arranged in single dense layer just below the surface. *Asci* cylindrical, long, stipitate, 8-spored and

measures 231–252 × 9.5–14 µm (Fig. 2G, H). *Ascospores* purple-brown, ellipsoid-inequilateral, aseptate, uniseriate and measures 24.3–31.6 × 7.9–10.5 µm (Fig. 2H).

Substrate and distribution – On decaying logs of *Terminalia bellirica*, sacred grove, Kottoli, Western Ghats, Karnataka (July 06, 2012; N.C. Karun: NCK # 057).

***Xylaria polymorpha*** (Pers.) Grev. Fl. Edin.: 355 (1824) (Fig 4F–I)

Arising in tufts or groups, annual, lignicolous, infrequent, taste and odor not distinctive and inedible.

Stromata at first irregularly clavate, greyish-black with smoky-white/ash-grey powdery deposits, on age becoming purple-black and then black with elongated, broad, cylindrical-clavate to irregular, bulged, warty, finely wrinkled, apex round fertile head and narrowing below into a brownish black, short, stout sterile stem firmly attached to the wood (sometimes the fruit bodies are sessile with short to long rooting bases/stipes), flesh white and brittle, ostiole papillate and stromata measures 3.2–8.4 cm tall × 0.8–2.2 cm thick.

Perithecia black (purple-black), sub-spherical, fully embedded in fertile head, 0.5–1 mm diam., and arranged in a single dense layer just below the surface. *Asci* cylindrical, long, stipitate, 8-spored and measures 165–210 × 8–14 µm. *Ascospores* purple-brown, aseptate, uniseriate and measures 10.5–14.5 × 3.9–4.7 µm (Fig. 2I).

Substrate and distribution – On degrading logs of *Terminalia bellirica* and *Toona ciliata* in Shola forest, Sampaje; Coffee agroforest, B'Shettigeri, Western Ghats, Karnataka (October 20, 2012; N.C. Karun: NCK # 058).

***Xylaria symploci*** Pande, Waingankar, Puneekar & Ranadive Indian J. For. 28 (3): 267 (2005)

(Fig 4J)

Solitary or in a group of 4–5, annual, particulous, rare, taste and odor not distinctive and inedible.

Stromata at first blackish, smooth, cylindrical-clavate with pale yellowish/yellowish-green conidial deposits, on age becoming black with long, cylindrical, finely warty, wrinkled, apex round fertile head and narrowing below into a concolorous, short to long sterile stem deeply embedded in soil by means of small to long rooting base, flesh white and tuberous, ostiole papillate and stromata measures 10.3–19.1 cm tall × 1.4–4.2 cm thick.

Perithecia blackish-brown, sub-spherical, innate, fully embedded in fertile head, 0.5–1 mm diam. and arranged in a single dense layer just below the surface. *Asci* cylindrical, long, stipitate, 8-spored and measures 105–130 × 10–12 µm. *Ascospores* purple-brown, fusiform, aseptate, uniseriate and measures 13.8–16.3 × 5.3–5.9 µm (Fig. 2J).

Substrate and distribution – On soil under the standing dead tree, Makutta forest reserve, Western Ghats, Karnataka (August 31, 2012; N.C. Karun: NCK # 059).

### Key to *Xylaria* found in the present study

Several keys are available for identification of *Xylaria* based on host plant species (fruits), substrate (soil, leaf/woody litter) and teleomorph/anamorph stages (stromatal structure, sporangia and ascospores), (e.g. Rogers & Samuels 1986, Lee et al. 2002, Rogers et al. 2008, Trierveiler-Pereira et al. 2009, Kshirsagar et al. 2009). The following key is based on the occurrence of nine *Xylaria* spp. on the different substrates in the current study:

- |  |                      |
|--|----------------------|
| 1a. Fruit body arising on humus and degrading leaves/kernels/pods/twigs/wood/log/stub ...  | 2                    |
| 1b. Fruit body arising on wood embedded in soil/termite mound .....  | 4                    |
| 2a. Fruit body arising exclusively on degrading leaves; hairy to slender and flexible with fertile grooved collars at junctures towards apex ..... | <i>X. filiformis</i> |
| 2b. Fruit body arising on humus/kernels/pods/twigs and having antler-shaped stromata.....  | <i>X. hypoxylon</i>  |

- 2c. Fruit body arising on wood, log and stub..... 3
- 3a. Fruit body irregularly club-shaped, medium to large, black with purple shade, short and stout stem..... *X. polymorpha*
- 3b. Fruit body sub-globose, small to medium, black with reddish-brown shade, short and stout Stem..... *X. obovata*
- 3c. Fruit body cylindrical to club-shaped, medium, smooth and black with short to long stem ..... *X. longipes*
- 3d. Fruit body cylindrical, small, dull-black, surface elevated, grooved and with short stem .....*X. multiplex*
- 4a. Fruit body arising on soil in the basin of standing dead tree; large, cylindrical, black with yellowish-green conidial deposits and short to long stem..... *X. symploci*
- 4b. Fruit body arising on active/inactive termite mounds..... 5
- 5a. Fruit body cylindrical, small to medium, black with round to acute apex; immature fruit body short to long and whip-like with pinkish-grey conidial deposit.....*X. nigripes*
- 5b. Fruit body cylindrical to fusoid, medium to long, black with round to obtuse apex; immature fruit body long and whip-like with smoky-white/ash conidial deposit *X. escharoidea*

## Discussion

Even though *Xylaria* are common on woody litter, three species were recovered from the abandoned termite mounds (*Xylaria acuminatilongissima*, *X. escharoidea* and *X. nigripes*) (Table 1). Termite combs serve as one of the prominent ecological niches of *Xylaria*, mostly owing to microclimatic conditions (temperature, humidity and carbon dioxide) favors growth of *Xylaria* (Guedegbe et al. 2009). Up to 69% of termite nests on incubation in the laboratory yielded *Xylaria* spp. in the South Africa showing their high prevalence (Visser et al. 2009). According to Hsieh et al. (2010), up to 20 species of *Xylaria* associated with termite nests. Rogers et al. (2005) pointed out that three species of *Xylaria* (*X. escharoidea*, *X. furcata* and *X. nigripes*) co-evolved with termites due to small size of spores. Interestingly, *X. nigripes* has been isolated from the gut of termites (*Odontotermes horni*) (Sreerama & Veerabhadrapa 1993) indicating close association of *Xylaria* with termites. In our study, *X. nigripes* was ectomycorrhizal on ornamental thorny climber *Bougainvillea spectabilis* in the west coast. Another interesting observation was that *X. hypoxylon* occurred extensively on the leaf litter, twigs and dead kernels of *Cassine glauca* in the coffee agroforest in Virajpet, Western Ghats, where abundant *C. glauca*-dependent dead stink bugs *Halyomorpha halys* colonized by the entomophagous fungus *Ophiocordyceps nutans* (Karun & Sridhar 2013). Further investigations on *Xylaria* provide exciting possibilities to explore their ecological niches, morphological diversity, pattern of distribution and valuable metabolites in future.

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