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Colonization and diversity of aquatic hyphomycetes in relation to decomposition of submerged leaf litter in River Kali (Western Ghats, India)

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Abstract

Dynamics of leaf chemistry, quantitative studies and decomposition of leaves by aquatic hyphomycetes in the Western Ghats is investigated in this paper. A total of 28 species (range, 19–28 spp.) of aquatic hyphomycetes were recovered from natural and submerged (banyan and cashew) leaf litter in Kaiga stream and Kadra dam of the Western Ghats over three seasons (monsoon, post-monsoon and summer) in 12 months of 2008–09. Higher species richness and conidial output was seen during the post-monsoon season and this corroborates with earlier studies. Among the top six species, five were common in different locations of the Western Ghats (*Anguillospora longissima*, *Flagellospora curvula*, *Lunulospora curvula*, *Triscelophorus acuminatus* and *T. monosporus*). Among the 12 less frequent species, seven also occurred in low frequency in other locations of the Western Ghats (*Clavariopsis aquatica*, *Dwayaangam cornuta*, *Flabellospora crassa*, *F. multiradiata*, *Ingoldiella hamata*, *Nawawia filiformis* and *Tricladium* sp.). Leaf litter decomposition resulted in elevation of nitrogen and decrease in phosphorus and total phenolics. Cellulase was higher in banyan than cashew leaves compared to xylanase and pectinase in stream and dam locations. The enzyme activity peaked within one or two weeks and subsequently remained steady with a few exceptions coinciding with increase in total nitrogen, decrease in total phenolics and leaf mass loss. Banyan and cashew leaf litter in Kaiga stream and Kadra dam falls in the slow decomposing category over three seasons (*k*, 0.0030-0.00.0050). Decomposition of banyan leaves (*k*, 0.0037-0.0050) was faster than cashew leaves (*k*, 0.0030-0.0043) in stream as well as dam sites. This was reflected in changes in leaf chemistry (slow decrease of organic carbon, phosphorus, phenolics and gradual increase in nitrogen), low enzyme activity (xylanase and pectinase), low fungal richness, conidial output and fungal diversity in dam location. Leaf mass of banyan and cashew was positively correlated with organic carbon, phosphorus and total phenolics, while negatively correlated with nitrogen and enzyme activity. Negative correlation between phenolics and enzymes reveals that the mass loss was dependent on the quantity and extent of leaching of phenolics. Overall, the assemblage of aquatic hyphomycetes on leaf litter in Kaiga stream and Kadra dam imitates other locations of the Western Ghats with variations in dynamics of leaf chemistry, decomposition and mass loss.

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Key words – Aquatic hyphomycetes – colonization – dam – decomposition – diversity – enzymes – stream – leaf chemistry – leaf litter – leaf mass loss – Western Ghats

Introduction

Aquatic hyphomycetes belong to polyphyletic group of fungi called freshwater hyphomycetes, amphibious fungi or Ingoldian fungi (Webster & Descals 1981, Bärlocher 1992a, Belliveau & Bärlocher 2005). Plant detritus in streams and rivers constitute up to 50-90% energy source of aquatic food web (Minshall 1967, Fisher & Likens 1973, Cummins et al. 1989, Triska & Cromack 1980). Aquatic hyphomycetes colonize and grow on the decaying leaf litter and produce huge quantity of conidia in lotic habitats (Bärlocher 2009). They produce multiradiate, sigmoid and conventional conidia. Identifications are mainly based on the ontogeny and characteristic morphology of conidia (Ingold 1975, Marvanová 1997, Gulis et al. 2005). The sticky conidial tips facilitate anchoring and colorization of the leaf litter and other organic matter (Webster 1959, Read et al. 1992, Jones 2006, Dang et al. 2007, Kearns & Bärlocher 2008). Aquatic hyphomycetes release many extracellular enzymes capable to degrade the polysaccharides of leaves, soften and improve palatability for aquatic fauna (Chandrashekar et al. 1991a, Bärlocher 2005, Gessner et al. 2007). Diversity of aquatic hyphomycetes in freshwaters is important for plant litter decomposition and several ecosystem functions (Bärlocher & Corkum 2003, Duarte et al. 2006). The major developments in the discovery and taxonomic studies on aquatic hyphomycetes from 1880 to 2005 have been documented by Krauss et al. (2011).

The fungal biomass in decaying leaf litter accounts to 63–100% of total microbial biomass (Gulis & Suberkropp 2003). Even though bacteria are capable of higher turnover of coarse particulate organic matter (CPOM) in streams, the fungal production is equivalent or higher than bacterial production (Weyers & Suberkropp 1996). Up to 18–23% of total detritus mass encompass fungal biomass and 80% of this biomass will be invested for conidial production in aquatic ecosystem (Suberkropp 1995, Gessner 1997, Methvin & Suberkropp 2003). Besides increase in biomass, aquatic hyphomycetes produce large numbers of conidia, which will be up to 8/µg detritus dry mass (Gessner 1997). More than 90% of conidia will be produced mainly by the top 1-4 core group species of aquatic hyphomycetes (frequency of occurrence ≥10%) (Bärlocher 1992b). Occurrence, interaction and ecosystem functions (e.g. succession, litter mass loss, biomass buildup and detoxification of xenobiotics) of aquatic hyphomycetes in leaf litter of lotic ecosystem are dependent on several factors like assemblage of fungal species, other aquatic microorganisms, aquatic fauna, water qualities and leaf litter qualities (Krauss et al. 2011).

Occurrence and diversity of aquatic hyphomycetes in the Western Ghats have been studied mainly by assessing water, foam and leaf litter (Sridhar et al. 1992, Raviraja et al. 1998a, Rajashekhar & Kaveriappa 2003). However, a few quantitative studies are available on conidial production by the aquatic hyphomycetes based on bubble chamber incubation (e.g. Raviraja et al. 1996, 1998b, Sridhar et al. 2010). With a few exceptions, detailed studies on water chemistry, leaf litter chemistry, leaf litter enzymes and leaf mass loss are lacking (e.g. Raviraja et al. 1996, 1998b). The main aim of this study is to evaluate the occurrence of aquatic hyphomycetes in the River Kali of the Western Ghats near Kaiga Nuclear Power Station to generate baseline data as this region will emerge in future as an industrial centre. In the current study, aquatic hyphomycetes in naturally submerged leaf litter and immersed leaf litter (banyan and cashew) in two locations of the River Kali (Kaiga stream and Kadra dam) have been investigated. To link the occurrence of aquatic hyphomycetes in leaf litter, water chemistry, leaf litter chemistry, leaf enzymes and leaf mass loss were assessed during different seasons (summer, monsoon and post-monsoon).

Materials and Methods

Study site

The River Kali originates in the Western Ghats ~900 m asl and flows westwards up to 160 km and joins the Arabian Sea near Karwar City. Kali River has two tributaries (Upper Kaneri and

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Tattihalla) and four dams are built across the rivers Supa, Bommanahalli, Kodasalli, and Kadra for electricity generation. The sampling locations selected for study at the River Kali (Kaiga stream: S1, S2 and S3; Kadra dam, D1, D2 and D3) are situated adjacent to the village Kaiga (~35 km east of Karwar; ~55−70 m asl; 14°50′−14°51′N, 74°24′−74°27′E). The Kaiga stream is a third order stream consists of sandy loam soil and rocky bottom. The Kadra dam receives water from many streamlets passing through wetlands. Average depth of sampling locations of Kaiga stream during sampling period ranged between 1.5 (S1) and 3.5 m (S3), while in dam sites ranged from 3.6 m (D3) to 13.8 m (D2). The sampling stream and dam locations consist of leaf litter, woody litter and roots of many forest trees species mainly *Artocarpus heterophyllus*, *Ficus benghalensis*, *F. racemosa*, *Syzygium caryophyllatum*, *Terminalia arjuna*, *T. paniculata* and *Xylia xylocarpa*.

Water samples

Water samples were collected five times (1, 2, 4, 6 and 8 weeks) in triplicates from each sampling sites during summer (April–May 2008), monsoon (August-September 2008) and post-monsoon (December 2008–January 2009) seasons (n=15 per season). Water temperature was assessed by mercury thermometer. The pH, electrical conductivity, turbidity and total dissolved solids were assessed at the sampling sites (Water Analyzer 371, Systronics, Gujarat, India). The water samples were fixed on the sampling sites to assess dissolved oxygen by Winkler's method (APHA 1995). Other parameters such as total alkalinity, total hardness, chloride, sulfate, nitrate, silica and magnesium were assessed as per the APHA (1995) methods. The calcium, sodium and potassium of water samples were estimated by flame-emission photometry (MK1/MK3, Systronics, India) (AOAC 1990). The vanadomolybdophosphoric acid method was employed to determine the total phosphorus by measuring the absorbance at 420 nm using KH_2PO_4 as standard (AOAC 1990).

Leaf litter

Naturally deposited decomposing leaf litter from each sampling site in three replicates during 1, 2, 4, 6 and 8 weeks in each season was collected (n=15 per season). After rinsing in water, different leaves were packed and punched into disks (1.5 cm diam.) using cork-borer. The disks were assessed for the colonization of aquatic hyphomycetes by bubble chamber incubation. The leaf disks (5-8 disks/sample) were incubated in 150 mL of sterile distilled water in 250 mL Erlenmeyer flasks. Water in flasks was aerated though Pasteur pipettes by an aquarium pump for up to 48 h (23±2°C). Aerated water was filtered through a Millipore filters (5 µm) and stained with aniline blue in lactophenol (0.1%). Each stained filter was cut into half, mounted on a microscope slide with lactic acid, and the conidia of aquatic hyphomycetes trapped on the filters were identified based on monographs and primary literature (Ingold 1975, Carmichael et al. 1980, Webster & Descals 1981, Nawawi 1985, Marvanová 1997, Santos-Flores & Betancourt-López 1997, Gulis et al. 2005).

Fungi

To assess the pattern of fungal colonization on immersed leaf litter, senescent and freshly fallen leaves of banyan (*Ficus Benghalensis* Linn.) and cashew (*Anacardium occidentale* L.) were collected from a single tree from the Kaiga forest during February 2008. They were air-dried up to 3–4 weeks (30°C) and soaked in water overnight and punched into disks (1.5 cm). Up to 15–20 disks were packed per nylon mesh bag (15 × 15 cm; mesh size, 1 mm) to introduce into the stream and dam locations. About 20 bags were prepared with pre-weighed disks to determine the mass loss. A total of 80 bags (numbered with plastic tags) of each leaf litter in four sets were immersed in sampling sites by tying the bags to nylon ropes and the ropes were fastened to nearby root or tree trunks. Out of them, leaf disks of about 20 bags each were used to assess the fungal colonization by bubble chamber incubation, leaf chemistry, leaf enzymes and leaf mass loss on sampling 1, 2, 4, 6 and 8 weeks in each season.

Leaf chemistry

The leaf disks were harvested during 1, 2, 4, 6 and 8 weeks were dried at 40–45°C and organic carbon, nitrogen, phosphorus, total phenolics and enzymes were analyzed.

Organic carbon

Walkley and Black's rapid titration method was employed to quantify organic carbon in leaf disks (Jackson 1973). Fifty mg leaf powder was taken in a 500 mL Erlenmeyer flask, 1N $K_2Cr_2O_7$ (5 mL) was added, after 5 min 90% H_2SO_4 (15 mL) was added and digested (30 min). Distilled water (100 mL) was added to the digested sample followed by addition of orthophosphate (85%; 5 mL) and the contents were titrated against ferrous ammonium sulphate (0.5 N) using diphenylamine indicator (0.5 mL).

Nitrogen

The dried leaf powder of banyan and cashew was digested for the estimation of nitrogen. Leaf samples (100 mg) with catalytic mixture (1 g) were digested in concentrated H_2SO_4 (10 mL) in a Kjeldahl flask (30 mL capacity) on a hot sand bath. After cooling, the contents were transferred to 100 mL volumetric flask, the Kjeldahl flask was rinsed twice with 20 mL distilled water and transferred to the volumetric flask and made up the volume to 100 mL (Chale 1993). The digest (10 mL) was transferred to micro-Kjeldahl distillation flask, NaOH (40%; 10 mL) was added and distilled. The liberated ammonia was collected in boric acid (2%; 10 mL) containing mixed indicator until attain 25 mL volume and titrated against dilute HCl (0.01N) (APHA 1995).

Phosphorus

Phosphorus was measured colorimetrically employing vanadomolybdo-phosphoric acid method (AOAC 1990). The banyan and cashew leaf samples were digested in tri-acid mixture (HNO_3, H_2SO_4 and $HClO_3$: 10:1:4). The digest was made up to 50 mL with *Milli-Q* water. The digest (3 mL) was mixed with vanado-molybdate reagent (10 mL), mixed thoroughly and made the volume to 50 mL. The absorbance of yellow color developed due to formation of vanadomolybdophosphoric acid was measured after 10 min at 420 nm (UV-VIS Spectrophotometer-118, SYSTRONICS, Ahmedabad, Gujarat, India) using reagent blank as the reference. Known concentrations of KH_2PO_4 served as standard.

Phenolics

The total phenolics of banyan and cashew leaf powders was determined by Rossett et al. (1982). Subsamples of leaf powder (100 mg) were extracted twice with methanol (50%; 5 mL) at 90ºC for 10 min in centrifuge tubes capped with marble. The pooled extracts were made up to 10 mL, mixed and 0.5 mL extract was diluted with distilled water (0.5 mL), treated with 2% Na_2CO_3 in 0.1N NaOH (5 mL). After 10 min, of Folin-Ciocalteus reagent (0.5 mL) (diluted 1:1 with distilled water) was added and the absorbance was read at 725 nm. Calibration curve was prepared by treating known concentration of tannic acid solutions similar to that of the sample as standard.

Enzymes

Harvested leaf disks (1, 2, 4, 6, 8 weeks) in five replicates were freeze-dried (OPERON, OPR- FDB-5003, Korea), powdered, and the enzymes (cellulase, xylanase and pectinase) were estimated colorimetrically (Nelson 1944, Somogyi 1952). Briefly, leaf powder (100 mg) were wetted with sterile distilled water (25 mL) for 30 min, filtered through Whatman # 1 filter paper, filtrates (0.5 mL) were mixed with acetate buffer (1 mL) and substrate (0.5% carboxymethyl cellulose or xylan or polygalacturonic acid; 1 mL) with a drop of toluene (to avoid bacterial growth) and incubated (1 h). The samples were boiled in water bath (10 min) for inactivation of enzymes, on cooling room temperature, Somogy's reagent (1 mL) and Nelson's reagent (0.5 mL) were added. The liberated reducing sugars were estimated spectrophotometrically at 620 nm with D-glucose or

D-xylose or D-galacturonic acid as standard. A boiled extract served as a blank and the enzyme activity was expressed as μg/mL/h.

Leaf mass loss

Pre-weighed leaf disks in randomly-sampled litter bags were harvested and rinsed to remove sediment and debris. The mass loss was determined by comparing initial mass (100%) before exposure and remaining mass after air-drying and corrected by exposure to 100°C for 24 h. Extra samples were used to create a correction factor for air dry mass-to-oven dry mass. The exponential decay coefficient, *k* was estimated by linear regression of ln-transformed data.

Data analysis

The frequency of occurrence (%) and relative abundance (%) of each fungus on natural, banyan and cashew leaves were determined:

Frequency of occurrence (%) = [(Number of leaf samples colonized) ÷ (Total Leaf samples examined)] × 100

Relative abundance (%) = [(Frequency of occurrence of a specific fungus) ÷ (Total of frequency of occurrence all fungi)] × 100

To compare the richness of fungi in natural, banyan and cashew leaf samples based on number of isolations and number of samples assessed, the expected number of species was calculated by rarefaction indices (Ludwig & Reynolds 1988). The expected number of species, $E_{(s)}$, in a random sample of *n* isolations taken from a total population of *N* isolations was estimated:

$$E_{(s)} = \sum_{i=1}^{s} \left\{ 1 - \left[\binom{N - n_i}{n} \Big/ \binom{N}{n} \right] \right\}$$

(where, n_i is the number of fungal isolations of the *i*th species).

The Shannon's diversity (H') (Magurran 1988) and Pielou's evenness (J') (Pielou 1975) of aquatic hyphomycetes in natural, banyan and cashew leaf samples were calculated:

$$H' = -\sum (p_i \ln p_i)$$

(where, p_i is the proportions of individual that species *i* contributes to the total number of individuals)

$$J' = (H' \div H'_{max})$$

(where, $H'_{\max} = \ln S$)

Sorensen's similarity coefficient (C_s) (%) of aquatic hyphomycetes among natural, banyan and cashew leaves in Kaiga stream and Kadra dam was calculated based on Chao et al. (2005):

$$C_S\ (\%) = (2 \times c \div a + b) \times 100$$

(where, *a* is total number of species in location 1; *b* is total number of species in location 2; *c* is number of species common to locations 1 and 2)

Exponential decay coefficient, *k*, were estimated for decomposition of banyan and cashew leaves in Kaiga stream and Kadra dam based on the exponential decay model proposed by Petersen and Cummins (1974) using MATLAB 6.5:

$$W_t = W_0 \cdot e^{-kt}$$

(where W_0 is the percentage of the initial leaf mass; W_t is the percentage of leaf mass remaining after time *t* (days) and *k* is a decay coefficient per day).

The time (days) required for the decomposition of half of the initial leaf mass (t_{50}) was determined:

$$t_{50} = \ln 2/k$$

The leaf decay coefficient (*k*) of Kaiga stream vs. Kadra dam was assessed by *t*-test using Statistica version 8.0. (StatSoft Inc. 2008).

The relationship between mass loss of banyan and cashew leaves vs. leaf chemistry (organic carbon, nitrogen, phosphorus and total phenolics) and leaf enzymes (cellulase, xylanase and pectinase) was assessed by Pearson's correlation (parameters: p values, two tailed; confidence intervals, 95%) (SPSS 6.0 Windows Student Version 3.5).

Results

Water parameters

The physicochemical data of water samples of Kaiga stream and Kadra dam locations in three seasons are summarized in Table 1. Many parameters differed substantially among the sites and seasons. For instance, the temperature and chloride were least during post-monsoon season, while the pH was slightly alkaline and it was least during summer in both locations. Sodium content also attained least during summer. The dissolved oxygen was higher in stream than dam (8–8.3 vs. 6.5–7 mg/L). The total alkalinity, total hardness, silica and magnesium contents were least during monsoon in both locations.

Fungal colonization

Occurrence and relative abundance of aquatic hyphomycetes on natural and submerged leaf litter have been given in Tables 2, 3 and 4. Banyan leaves consists of highest number of species (29 spp.) than natural leaves (23 spp.) and cashew leaves (19 spp.). Six species (*Anguillospora longissima, Flagellospora curvula, Lunulospora curvula, Triscelophorus acuminatus, T. konajensis* and *T. monosporus*) were among the top 10 species on natural leaves and submerged leaves in both locations. Twelve species (*Alatospora acuminata, Clavariopsis aquatica, Dimorphospora foliicola, Dwayaangam cornuta, Flabellospora crassa, F. multiradiata, Helicomyces scandens, Ingoldiella hamata, Nawawia filiformis, Synnematophora constricta, Tricladium* sp. and *Tumularia aquatica*) were below 5% frequency of occurrence either in natural leaves and or in submerged leaves. However, the natural leaves consists of only three species with <5% frequency of occurrence compared to banyan (6 spp.) and cashew (7 spp.) leaves.

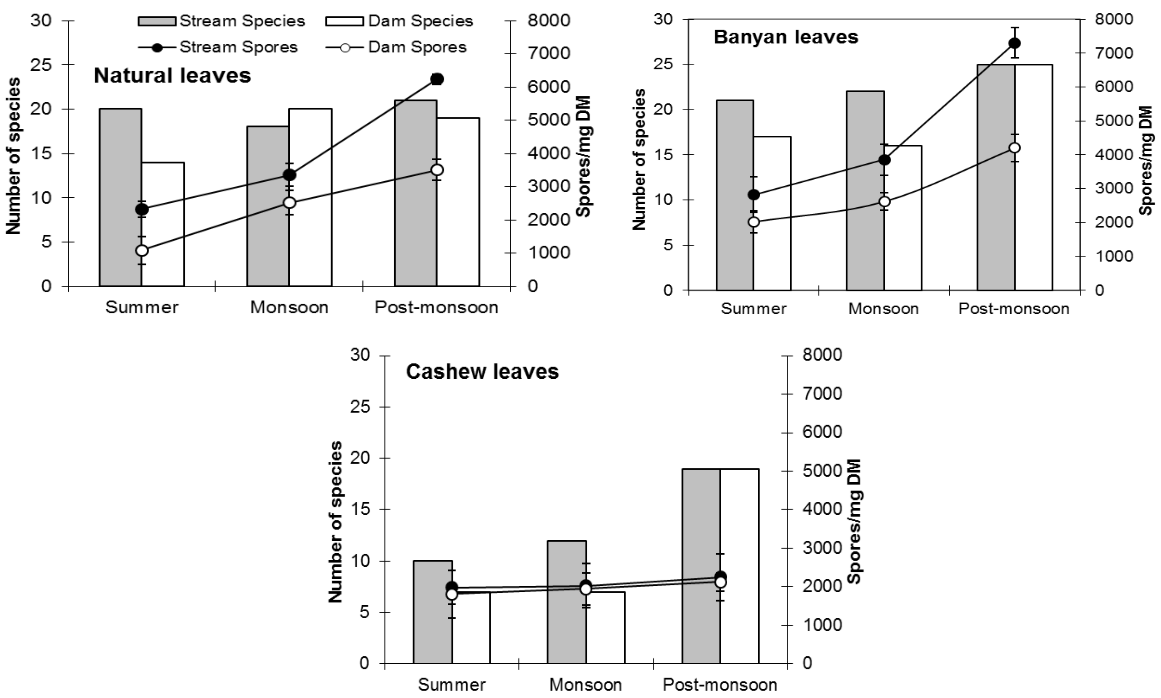

Fig. 1 – Species richness and conidial output of aquatic hyphomycetes in natural and immersed leaves (banyan and cashew) in Kaiga stream and Kadra dam.

Table 1 Physical and chemical properties of Kaiga stream and Kadra dam (in parenthesis) (n=15, mean±SD)

	Summer	**Monsoon**	**Post-monsoon**
Temperature (°C)	25.6±3.7 (32.4±1.0)	24.9±2.1 (32.1±1.2)	21.1±2.0 (31.1±1.6)
pH	7.3±0.3 (7.1±0.3)	7.8±0.4 (7.5±0.3)	7.5±0.4 (7.4±0.4)
Conductivity (µS/cm)	66.5±12.3 (65.8±14.8)	52.5±8.7 (75.1±10.7)	67.5±16.7 (90.1±20.5)
Turbidity (NTU)	2.9±0.4 (3.1±0.4)	3.3±1.4 (12.3±2.3)	2.7±0.7 (4.1±1.7)
Total dissolved solids (mg/L)	33.9±6.6 (32.7±6.2)	26.6±4.3 (39.4±8.2)	34.4±7.9 (46.9±11.6)
Dissolved oxygen (mg/L)	8.0±0.4 (6.5±0.3)	8.2±0.3 (7.0±0.4)	8.3±0.2 (6.8±0.3)
Total alkalinity (mg/L)	23.3±4.7 (24.0±)3.1	16.3±2.1 (23.4±5.1)	25.1±4.9 (31.5±5.4)
Total hardness (as $CaCO_3$)	27.8±8.1 (27.8±3.1)	18.4±2.3 (26.1±6.0)	26.4±7.6 (28.6±5.0)
Chloride (mg/L)	5.6±1.2 (5.7±1.5)	4.6±1.1 (5.1±0.8)	4.3±0.8 (4.9±1.1)
Sulfate (mg/L)	2.9±0.3 (2.7±0.1)	2.3±0.8 (2.9±0.4)	2.3±0.6 (3.0±0.3)
Nitrate (mg/L)	1.3±0.2 (1.4±0.2)	1.3±0.2 (1.2±0.1)	1.3±0.3 (1.2±0.1)
Silica (mg/L)	11.6±2.3 (10.3±1.7)	9.1±3.6 (9.8±2.0)	9.4±1.6 (10.5±1.5)
Magnesium (mg/L)	4.4±2.0 (3.8±0.7)	2.6±0.8 (3.2±0.9)	3.8±0.9 (3.3±0.9)
Calcium (mg/L)	3.9±0.4 (4.8±0.4)	3.6±1.6 (5.6±2.3)	4.4±1.8 (6.0±0.7)
Sodium (mg/L)	3.6±1.7 (3.2±0.9)	3.7±1.1 (4.1±1.4)	4.4±2.1 (6.4±2.2)
Potassium (mg/L)	0.2±0.04 (1.2±0.02)	0.4±0.04 (0.5±0.2)	0.4±0.04 (0.3±0.1)
Phosphate (µg/L)	10.2±3.3 (10.1±3.4)	6.6±0.7 (6.5±1.2)	6.8±0.4 (5.5±0.7)

Number of species on natural leaves was highest during post-monsoon in stream, while during monsoon in dam (Fig. 1, Table 2). In both locations in natural leaves, the conidial output was highest during post-monsoon. The species richness and conidial output were highest during post-monsoon season in banyan and cashew leaves in both locations (Table 3, 4). Rarefaction indices revealed that the banyan leaves in stream possess highest species richness (43 spp.) out of a 75 random samples followed by natural leaves (42 spp.) in Kaiga stream, while it was least in cashew leaves of dam (30 spp.) (Table 5). Banyan leaves of stream showed the highest and extended species richness curve, while it was the lowest and truncated in cashew leaves of dam (Fig. 2). The Shannon diversity also followed similar pattern of rarefaction indices. The Sorenson's similarity was highest between natural leaves of stream and dam locations (100%), so also in cashew leaves of stream and dam (100%) (Table 6). In rest of the combinations, the similarity was ranged between 80% and 98.2%.

Table 2 Number of occurrences (out of 15 samples of natural leaves), frequency of occurrence (FO %) and relative abundance (RA %) of aquatic hypohomycetes fungi on naturally deposited leaf litter during summer, monsoon and post-monsoon in Kaiga stream and Kadra dam (in parenthesis)

	Summer	**Monsoon**	**Post-monsoon**	**FO (%)**	**RA (%)**
Lunulospora curvula Ingold	11 (8)	11 (9)	13 (5)	77.7 (48.9)	9.2 (11.6)
Triscelophorus monosporus Ingold	14 (8)	9 (4)	11 (5)	75.5 (37.7)	9.0 (8.9)
Triscelophorus acuminatus Nawawi	9 (6)	11 (7)	8 (3)	62.2 (35.5)	7.4 (8.4)
Anguillospora longissima (Sacc. & P. Syd.) Ingold	5 (2)	6 (8)	9 (10)	44.4 (44.4)	5.3 (10.5)
Triscelophorus konajensis K.R. Sridhar & Kaver.	5 (2)	8 (6)	12 (5)	55.5 (28.9)	6.6 (6.9)
Flagellospora curvula Ingold	9 (8)	6 (4)	6 (2)	46.6 (31.1)	5.5 (7.4)
Lunulospora cymbiformis K. Miura	6 (2)	5 (1)	11 (8)	48.8 (24.4)	5.8 (5.8)
Tripospermum myrti (Lind) S. Hughes	5 (2)	2 (6)	5 (8)	26.6 (35.5)	3.2 (8.4)
Clavariopsis aquatica de Wild.	6 (2)	8	10	53.3 (4.4)	6.3 (1.1)
Synnematophora constricta K.R. Sridhar & Kaver.	3 (1)	8 (2)	9 (2)	44.4 (11.1)	5.3 (2.6)
Flabellospora verticillata Alas.	6 (1)	3 (1)	9 (4)	40.0 (13.3)	4.7 (3.2)
Anguillospora crassa Ingold	5	8 (3)	5 (2)	40.0 (11.1)	4.7 (2.6)
Dimorphospora foliicola Tubaki	5	3 (2)	8 (2)	35.5 (8.9)	4.2 (2.1)
Flabellospora multiradiata Nawawi	3 (1)	6	8 (2)	37.7 (6.7)	4.5 (1.6)
Campylospora chaetocladia Ranzoni	(2)	7 (2)	6 (1)	28.9 (11.1)	3.4 (2.6)
Lateriramulosa uni-inflata Matsush.	4 (2)	3	6 (3)	28.9 (11.1)	3.4 (11.1)
Flabellospora crassa Alas.	–	4 (2)	8 (3)	26.6 (11.1)	3.2 (2.6)
Clavariana aquatica Nawawi	2	(3)	5 (2)	15.5 (11.1)	1.8 (2.6)
Cylinodrocarpon sp.	2	5 (2)	(3)	15.5 (11.1)	1.8 (2.6)
Lunulospora sp.	2	(3)	5	15.5 (6.7)	1.8 (1.6)
Ingoldiella hamata D.E. Shaw	2	(1)	5	15.5 (2.2)	1.8 (0.5)
Tumularia aquatica (Ingold) Descals & Marvanová	–	(2)	2 (3)	4.4 (11.1)	0.5 (2.6)
Nawawia filiformis (Nawawi) Marvanová	2	(2)	–	4.4 (4.4)	0.5 (1.1)

Changes in leaf chemistry

The initial organic carbon content was higher in cashew than banyan leaves (Fig. 3). It dropped less quickly in stream banyan leaves during summer, while more quickly in cashew leaves in dam during summer and stream during post-monsoon. At the end of 56 days, both leaf litter attained more or less same level of organic carbon.

Table 3 Number of occurrences (out of 15 bags with leaf disks), frequency of occurrence (FO %) and relative abundance (RA %) of aquatic hypohomycetes on submerged leaf disks of banyan (*Ficus benghalensis*) during summer, monsoon and post-monsoon in Kaiga stream and Kadra dam (in parenthesis)

	Summer	**Monsoon**	**Post-monsoon**	**FO (%)**	**RA (%)**
Lunulospora curvula Ingold	10 (8)	13 (7)	14 (11)	82.1 (57.7)	11.1 (12.0)
Triscelophorus acuminatus Nawawi	8 (7)	8 (10)	9 (6)	55.5 (51.1)	7.5 (10.7)
Flagellospora curvula Ingold	9 (3)	8 (3)	10 (7)	59.9 (28.9)	8.1 (6.0)
Triscelophorus monosporus Ingold	7 (2)	5 (3)	9 (10)	46.6 (33.3)	6.3 (6.9)
Anguillospora longissima (Sacc. & P. Syd.) Ingold	6 (2)	9 (4)	9 (5)	53.3 (24.4)	7.2 (5.1)
Anguillospora crassa Ingold	2 (2)	3 (4)	9 (7)	31.1 (28.9)	4.2 (6.0)
Clavariana aquatica Nawawi	3	5 (2)	8 (7)	35.5 (20.0)	4.8 (4.2)
Triscelophorus konajensis K.R. Sridhar & Kaver.	2	1 (3)	9 (7)	26.6 (22.2)	3.6 (4.6)
Tripospermum myrti (Lind) S. Hughes	(2)	3 (5)	5 (6)	17.8 (28.9)	2.4 (6.0)
Flabellospora verticillata Alas.	1 (3)	2	5 (6)	17.8 (20.0)	2.4 (4.2)
Dimorphospora foliicola Tubaki	5 (1)	2	6 (2)	28.9 (6.7)	3.9 (1.4)
Flabellospora crassa Alas.	–	3 (1)	5 (7)	17.8 (17.8)	2.4 (3.7)
Campylospora parvula Kuzuha	2 (1)	3	5 (4)	22.2 (11.1)	3.0 (2.3)
Clavariopsis aquatica de Wild.	2	(5)	4 (4)	13.3 (20.0)	1.8 (4.2)
Cylinodrocarpon sp.	2	(3)	4 (2)	13.3 (11.1)	1.8 (2.3)
Campylospora chaetocladia Ranzoni	3 (2)	3 (5)	8	31.1 (15.5)	4.2 (3.2)
Lunulospora sp.	(2)	3 (1)	8 (6)	24.4 (20.0)	3.3 (4.2)
Lunulospora cymbiformis K. Miura	5	4 (2)	6 (3)	33.3 (11.1)	4.5 (2.3)
Tumularia aquatica (Ingold) Descals & Marvanová	1 (1)	–	8 (3)	20.0 (8.9)	2.7 (1.9)
Nawawia filiformis (Nawawi) Marvanová	(2)	4	6	22.2 (4.4)	3.0 (0.9)
Ingoldiella hamata D.E. Shaw	(2)	5	2 (3)	15.5 (11.1)	2.1 (2.3)
Lateriramulosa uni-inflata Matsush.	(1)	2	4 (2)	13.3 (6.7)	1.8 (1.4)
Synnematophora constricta K.R. Sridhar & Kaver.	2	4 (2)	(1)	13.3 (6.7)	1.8 (1.4)
Flabellospora multiradiata Nawawi	–	4	2 (1)	13.3 (2.2)	1.8 (0.5)
Alatospora acuminata Ingold	1	4	(2)	11.1 (4.4)	1.5 (0.9)
Tricladium sp.	2	–	3 (1)	11.1 (2.2)	1.5 (0.5)
Dwayaangam cornuta Descals	2 (1)	–	2 (1)	8.9 (4.4)	1.2 (0.9)
Helicomyces scandens Morgan	1	–	–	2.2	0.3

Table 4 Number of occurrences (out of 15 bags with leaf disks), frequency of occurrence (FO %) and relative abundance (RA %) of aquatic hypohomycetes on submerged leaf disks of cashew (*Anacardium occidentale*) during summer, monsoon and post-monsoon in Kaiga stream and Kadra dam (in parenthesis)

	Summer	**Monsoon**	**Post-monsoon**	**FO (%)**	**RA (%)**
Lunulospora curvula Ingold	11 (9)	10 (4)	15 (10)	79.9 (51.1)	16.3 (25.3)
Triscelophorus acuminatus Nawawi	9 (2)	8 (2)	9 (6)	57.7 (22.2)	11.8 (11.0)
Triscelophorus konajensis K.R. Sridhar & Kaver.	5 (3)	8 (2)	10 (3)	51.1 (17.8)	10.4 (8.8)
Anguillospora longissima (Sacc. & P. Syd.) Ingold	5 (2)	7 (3)	5 (1)	37.7 (13.3)	7.7 (6.6)
Campylospora chaetocladia Ranzoni	–	5 (1)	8 (5)	28.9 (13.3)	5.9 (6.6)
Flagellospora curvula Ingold	2 (1)	5	6 (3)	28.9 (8.9)	5.9 (4.4)
Triscelophorus monosporus Ingold	4	3	8 (2)	33.3 (4.4)	6.8 (2.2)
Clavariana aquatica Nawawi	–	5	8 (3)	28.9 (6.7)	5.9 (3.3)
Lunulospora cymbiformis K. Miura	3 (1)	2	6 (1)	24.4 (8.9)	5.0 (2.2)
Anguillospora crassa Ingold	2	(3)	5 (2)	15.5 (11.1)	3.2 (5.5)
Flabellowpora verticillata Alas.	–	2 (1)	2 (4)	8.9 (11.1)	1.8 (5.5)
Tripospermum myrti (Lind) S. Hughes	(1)	2	4 (2)	13.3 (6.7)	2.7 (3.3)
Dimorphospora foliicola Tubaki	–	–	7 (2)	15.5 (4.4)	3.2 (2.2)
Clavariopsis aquatica de Wild.	1	–	5 (2)	13.3 (4.4)	2.7 (1.1)
Flabellospora multiradiata Nawawi	–	–	6 (2)	13.3 (4.4)	2.7 (2.2)
Nawawia filiformis (Nawawi) Marvanová	2	–	4 (1)	13.3 (2.2)	2.7 (4.4)
Ingoldiella hamata D.E. Shaw	–	–	5 (2)	11.1 (4.4)	2.3 (2.2)
Flabellospora crassa Alas.	–	–	3 (2)	6.7 (4.4)	1.4 (2.2)
Synnematophora constricta K.R. Sridhar & Kaver.	–	1	3 (1)	8.9 (2.2)	1.8 (1.1)

The initial nitrogen content was higher in banyan than cashew leaves. In both leaves and locations, the nitrogen increased. Nitrogen was elevated more quickly by attaining the highest in banyan leaves in both locations during post-monsoon. The initial total phosphorus was higher in banyan leaves than cashew leaves and decreased subsequently. Its decrease was faster (within 1 or 2 weeks) in both leaves and locations during post-monsoon than summer and monsoon seasons with subsequent increase or steady state. The initial total phenolics were higher in cashew than banyan leaves. It decreased more quickly in cashew compared to banyan leaves.

Changes in enzymes of banyan and cashew leaf during decomposition in different seasons are given Figure 4. Cellulase of banyan and cashew leaves swiftly elevated within one or two weeks in both locations. Subsequently it was stable or attained same level at the end of 56 days with an exception. Cellulase in banyan leaves gradually decreased after two weeks in stream during monsoon. Xylanase generally attained a peak within 1–4 weeks with a few exceptions (banyan in stream during summer elevated slowly; banyan in stream during monsoon attained highest on 56 days). Pectinase in banyan showed a peak during second or fourth or eighth week. In cashew leaves, it showed a peak in two weeks (except for cashew leaves in dam during summer).

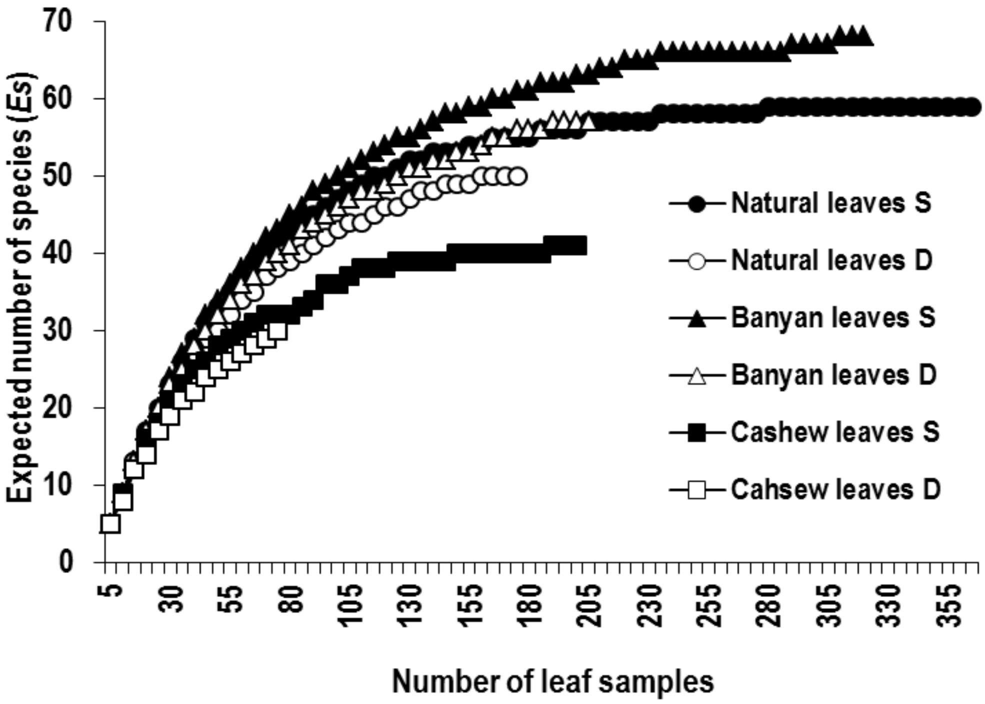

Fig. 2 – Expected number of species of aquatic hyphomycetes in natural and submerged leaf litter in Kaiga stream (S) and Kadra dam (D).

Table 5 Species richness and diversity aquatic hyphomycetes in leaf litter in Kaiga stream and Kadra dam

	Natural leaves		Banyan leaves		Cashew leaves	
	Stream	**Dam**	**Stream**	**Dam**	**Stream**	**Dam**
Species richness	23	23	28	27	19	19
Expected number of species, $E_{(s75)}$*	42	38	43	40	32	30
Shannon diversity	4.222	4.134	4.512	4.379	3.837	3.725
Pielou's evenness	0.947	0.914	0.932	0.911	0.920	0.877

Note: *Out of isolations from 75 random leaf samples

Table 6 Sorensen's similarity index (%) of aquatic hyphomycetes in leaf litter in Kaiga stream and Kadra dam (NS, natural leaves in stream; ND, natural leaves in dam; BS, Banyan leaves in stream; BD, Banyan leaves in dam; CS, Cashew leaves in stream; CD, Cashew leaves in dam)

	ND	BS	BD	CS	CD
NS	100	86.3	80	90.5	90.5
	ND	86.3	88	90.5	90.5
		BS	98.2	80.9	80.9
			BD	82.6	82.6
				CS	100

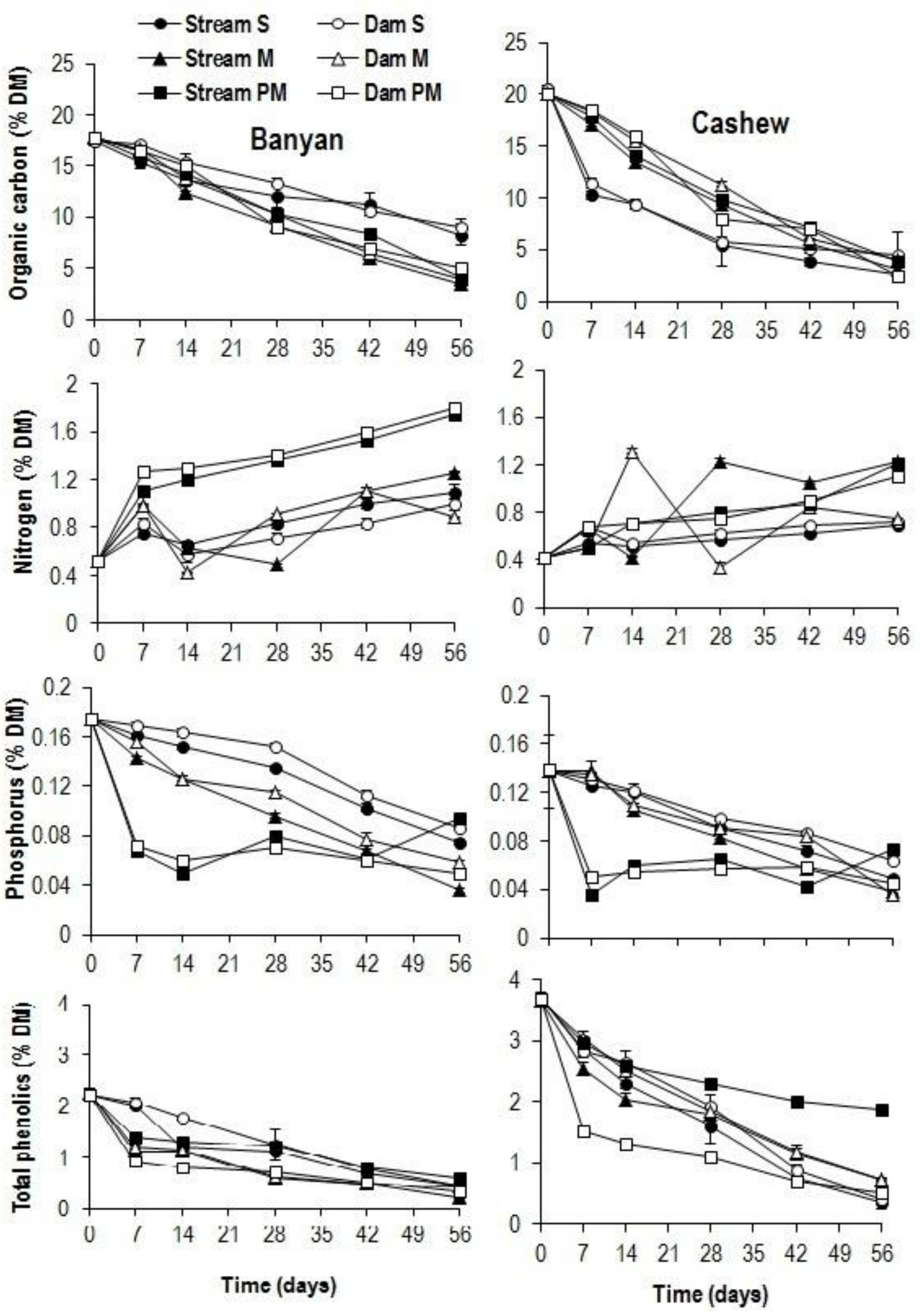

Fig. 3 – Changes in chemistry of banyan and cashew leaf litter in different seasons (S, summer; M, monsoon; PM, post-monsoon) in Kaiga stream and Kadra dam.

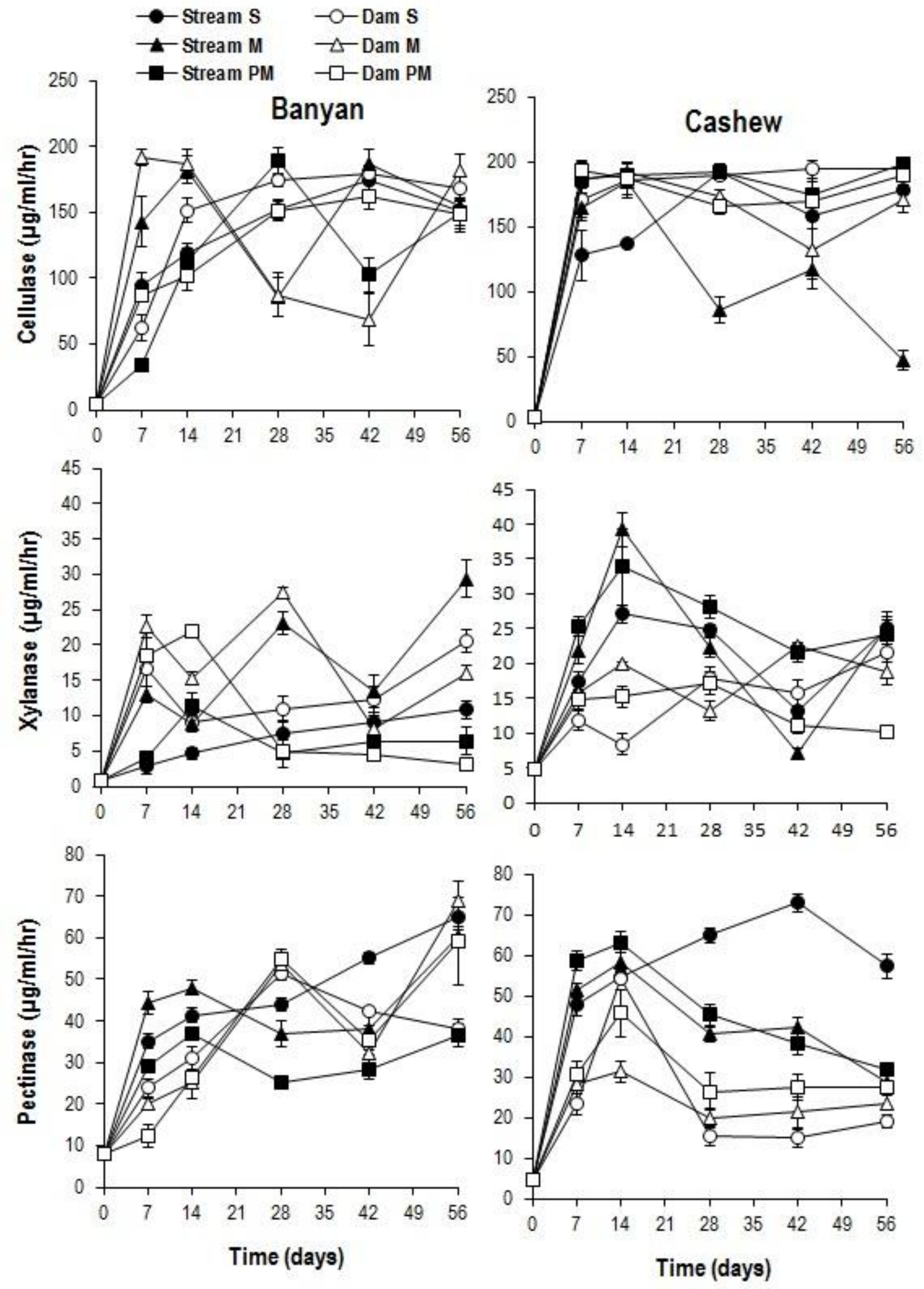

Fig. 4 – Enzyme profile of banyan and cashew leaf litter in different seasons (S, summer; M, monsoon; PM, post-monsoon) in Kaiga stream and Kadra dam.

Changes in leaf mass

Banyan leaf mass in both locations decreased gradually with a few exceptions (Fig. 5). During summer in stream, banyan mass lost more quickly, while it was slow during post-monsoon. Except for cashew leaves during summer, rest of the samples lost mass gradually in dam.

The estimated daily exponential decay coefficient (*k*) of banyan in stream ranged between 0.0037 (post-monsoon) and 0.0050 (monsoon), while in dam it was ranged between 0.0042 (post-monsoon) and 0.0048 (summer) (Table 7). In cashew leaves, the decay rates in stream ranged between 0.0030 (post-monsoon) and 0.0043 (monsoon), while in dam it was between 0.0032 (monsoon) and 0.0039 (summer). The decay coefficient was significantly differed in banyan leaves between stream and dam during monsoon and post-monsoon, while in cashew leaves it was significant only during monsoon (*t*-test). The banyan leaves in stream lost 50% mass (t_{50}) more quickly during monsoon (139 days) compared to summer (144 days) and post-monsoon (189 days), while in dam it was during summer (145 days) than monsoon (185 days) and post-monsoon (165 days). The t_{50} of cashew leaves followed similar pattern as seen in banyan leaves.

Table 8 gives the correlation coefficients between leaf mass remaining against the changes in leaf chemistry and leaf enzymes. The banyan leaf mass was positively correlated with organic carbon ($p<0.01$), phosphorus (dam site, $p<0.05$) and total phenolics ($p<0.01$), while it was negatively correlated with nitrogen, cellulase ($p<0.05$), xylanase and pectinase ($p<0.01$) of both locations. The total phenolics of banyan leaves was positively correlated with organic carbon ($p<0.01$) and phosphorus ($p<0.01$), while it was negatively correlated with nitrogen (stream, $p<0.05$; dam, $p<0.01$), cellulase (stream, $p<0.05$), xylanase (stream, $p<0.01$) and pectinase (stream, $p<0.01$; dam, $p<0.05$) in both locations. The remaining leaf mass of cashew was positively correlated with organic carbon ($p<0.01$), phosphorus (stream, $p<0.01$) and total phenolics (stream, $P<0.01$; dam, $p<0.05$), while negatively correlated with cellulase (dam, $p<0.05$), xylanase and pectinase in both locations. The total phenolics of cashew leaves was positively correlated with organic carbon ($p<0.01$) and phosphorus (stream, $p<0.05$; dam, $p<0.01$), while negatively correlated with nitrogen (dam, $p<0.01$), cellulase, xylanase and pectinase in both locations.

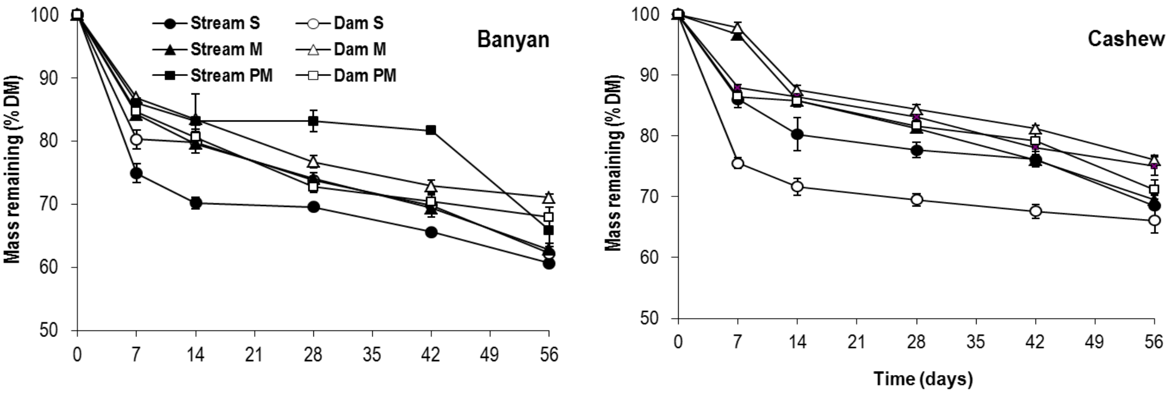

Fig. 5 – Mass loss of banyan and cashew leaf litter in different seasons (S, summer; M, monsoon; PM, post-monsoon) in Kaiga stream and Kadra dam.

Discussion

The mean water temperature was higher in Kadra dam in all seasons than Kaiga stream. The mean elevation of temperature in dam ranged between 8 and 10°C. Temperature regime of dam is equivalent or comparable to earlier studies in discharge site of Kali River (range, 27.5–31°C) (Sridhar et al. 2010a) and higher than incubation of leaf litter collected from upstream site (24–28°C) of Kali River yielded 15 species of aquatic hyphomycetes and 513–520 conidia/mg (Sridhar et al. 2010a).

Table 7 Statistics of leaf mass loss rates (*k*, daily exponential decay rate; R^2, coefficient of determination; t_{50}, estimated time in days for 50% mass loss)

		Summer	Monsoon	Post-monsoon
Banyan leaves				
Kaiga stream	k	0.0048[a]	0.0050[a]	0.0037[a]
	R^2	0.579	0.813	0.755
	t_{50}	144	139	189
Kadra dam	k	0.0048[a]	0.0038[b]	0.0042[b]
	R^2	0.758	0.755	0.712
	t_{50}	145	185	165
Cashew leaves				
Kaiga stream	k	0.0037[a]	0.0043[a]	0.0030[a]
	R^2	0.718	0.895	0.789
	t_{50}	189	161	234
Kadra dam	k	0.0039[a]	0.0032[b]	0.0033[a]
	R^2	0.471	0.844	0.791
	t_{50}	180	218	211

Note: *k* between locations with different letters indicate significant difference (*t*-test, $p<0.01$)

Increase of temperature of bubble chambers to 31, 33, 36°C resulted in decreased species richness (10, 5, 2 spp., respectively) as well as conidial output (460, 105, 25 conidia/mg, respectively) and no conidia released at 38°C. This study also corroborates with studies on aquatic hyphomycetes of two thermal springs of the Western Ghats (Chandrashekar et al. 1991b, Rajashekhar & Kaveriappa 1996). It is necessary to simulate the conditions of the natural habitats in laboratory microcosms with dam/stream water to assess the impact of temperature and other factors on the functions of aquatic hyphomycetes (e.g. growth and sporulation). Even though aquatic hyphomycetes (vegetative phase) tolerate elevated temperatures, their sporulation (reproductive phase) potential suffers (e.g. Sridhar et al. 2010a).

The pH of stream and dam locations was alkaline (range, 7.1-7.8) and similar to temperature regimes of the Kali River at high altitude and low altitude locations (543 m asl, pH, 7.8; 235 m asl, pH 7.45; 222 m asl, pH 7.3; 80 m asl, pH 7.21-7.24) (Rajashekhar & Kaveriappa 2003, Madoddi et al. 2009, Sridhar et al. 2010a), River Payaswini (500 m asl, pH 7.1) and River Kollur (350 m asl, pH 7.1) (Raviraja et al. 1998a), Sampaje stream (500 m asl, pH 7.1-7.4; 510 m asl, pH 7.2) (Raviraja et al. 1996, Sridhar et al. 2010b), Bagamandala stream (560 m asl, pH 7.2), Agumbe stream (960 m asl, pH 7.2; 970 m asl, pH 7.4) and Shivpura stream (460 m asl, pH 7.3) (Sridhar et al., 2010b). The pH of stream and dam locations is comparable to 19 out of 21 lotic habitats of the Western Ghats (7.1–7.8 vs. 7.2–8.8) (Rajashekhar & Kaveriappa 2003).

The dissolved oxygen in dam was lower than stream (6.5–7 vs. 8–8.3 mg/L) and an earlier study also showed low dissolved oxygen in discharge site in River Kali (3.7–5 mg/L) (Sridhar et al. 2010a). Dissolved oxygen in stream is comparable to some of the Western Ghat rivers (8–8.3 vs. 7.5–8.1 mg/L) (Maddodi et al. 2009). However, several lotic water bodies of the Western Ghats showed lower dissolved oxygen (3.3–4 mg/L) (Rajashekhar & Kaveriappa 2003). The low dissolved oxygen (3.3–4 mg/L) resulted in low species richness compared to high dissolved oxygen (6–7 mg/L) in Western Ghat streams with positive correlation (Rajashekhar & Kaveriappa 2003). Wood-Eggenschwiler & Bärlocher (1983) showed significant correlations between species richness and several water parameters (pH, conductivity, alkalinity, calcium and magnesium concentrations). They also indicated that factors like temperature, water flow and competition among fungi are also responsible for variation in species richness. However, Bärlocher (1987) did not find any correlation between species richness and water parameters of 10 soft water streams of eastern Canada. But, the combined data of 16 streams of France, Germany and Switzerland showed a significant negative correlation between species richness and pH (Wood-Eggenschwiler & Bärlocher 1983, Bärlocher 1987).

Table 8 Pearson correlation coefficients between leaf mass remaining vs. leaf chemistry and enzymes in Kaiga stream and Kadra dam (in parenthesis)

Banyan leaves	**Organic Carbon**	**Nitrogen**	**Phosphorus**	**Total Phenolics**	**Cellulase**	**Xylanase**	**Pectinase**
Mass remaining	0.723** (0.784**)	-0.163 (-0.454)	0.320 (0.587*)	0.767** (0.748**)	-0.617* (-0.536*)	-0.450 (-0.123)	-0.823** (-0.731**)
Organic Carbon		-0.489 (-0.503*)	0.638** (0.727**)	0.863** (0.822**)	-0.557* (-0.353)	-0.556* (0.103)	-0.431 (-0.790**)
Nitrogen			-0.571* (-0.773**)	-0.357 (-0.632**)	0.241 (0.063)	-0.088 (-0.255)	-0.030 (0.287)
Phosphorus				0.656** (0.875**)	-0.278 (-0.197)	-0.530* (0.125)	-0.279 (-0.445)
Total Phenolics					-0.616* (-0.435)	-0.700** (-0.137)	-0.674** (-0.610*)
Cellulase						0.293 (0.214)	0.606* (0.477)
Xylanase							0.525* (0.117)

Cashew leaves	**Organic Carbon**	**Nitrogen**	**Phosphorus**	**Total Phenolics**	**Cellulase**	**Xylanase**	**Pectinase**
Mass remaining	0.952** (0.760**)	-0.547* (-0.500*)	0.663** (0.368)	0.885** (0.619*)	-0.264 (-0.537*)	-0.138 (-0.238)	-0.224 (-0.069)
Organic Carbon		-0.556* (-0.429)	0.489 (0.436)	0.875** (0.675**)	-0.278 (-0.357)	0.000 (-0.255)	-0.189 (0.152)
Nitrogen			-0.493 (-0.653**)	-0.475 (-0.724**)	-0.0129 (0.226)	-0.069 (0.070)	-0.335 (0.057)
Phosphorus				0.533* (0.901**)	-0.160 (-0.389)	-0.177 (-0.339)	-0.155 (-0.121)
Total Phenolics					-0.217 (-0.487)	-0.046 (-0.451)	-0.314 (-0023)
Cellulase						0.352 (0.455)	0.542* (0.488)
Xylanase							0.457 (-0.066)

Note: *, Correlation is significant at the 0.05 level (2-tailed)
**, Correlation is significant at the 0.01 level (2-tailed)

Other parameters like total alkalinity, total hardness, silica and magnesium were least during monsoon in both locations. Rest of the parameters showed variations between seasons as well as locations. The present study reveals that at least some of the water parameters of stream and dam are not drastically different from other locations of the Western Ghats. The change in physicochemical features of the lotic waters of the Western Ghats depends on the season. Besides the changes in temperature regime, pH, oxygen, conductivity and other chemical parameters may be governed by the periodic episodes of floods through the geologic terrain. It seems that the water chemistry will be dependent on the input of organic matter either throughout the year (evergreen) or seasonally (deciduous) as mosaic of vegetation exists in the Western Ghats. There is clear cut evidence that the water chemistry and species richness of aquatic hyphomycetes from mountain, mid-altitude, foot hill and coastal streams (Sridhar et al. 1992, Raviraja et al. 1998a). Natural calamities and human interference (e.g. severe monsoon, forest fire, agricultural practices, mining and input of organic matter) may influence the water chemistry and in turn the structure and functions of aquatic hyphomycetes.

Among the top six species of aquatic hyphomycetes found in the present study, five were also common in different locations of the Western Ghats (*Anguillospora longissima, Flagellospora curvula, Lunulospora curvula, Triscelophorus acuminatus* and *T. monosporus*) (Sridhar et al. 1992, Rajashekhar & Kaveriappa 2003). *Anguillospora longissima, Lunulospora curvula, Triscelophorus acuminatus* and *T. monosporus* occurred in high frequency in different locations of Kali River (Maddodi et al. 2009) coincides with a recent study (Sridhar et al. 2010a). Among the 12 less frequent species in the present study, seven species (*Clavariopsis aquatica, Dwayaangam cornuta, Flabellospora crassa, F. multiradiata, Ingoldiella hamata, Nawawia filiformis* and *Tricladium* sp.) were also less frequent in the Western Ghats (Raviraja et al. 1998a). *Clavariopsis aquatica* and *Nawawia filiformis* occurred in low frequency in only 3-4 locations out of 21 locations of the Western Ghats (Rajashekhar & Kaveriappa 2003). *Alatospora acuminata, Clavariopsis aquatica, Flabellospora crassa, F. multiradiata, Ingoldiella hamata, Tricladium* sp. and *Tumularia aquatica* were also less frequent in Kali River (Maddodi et al. 2009, Sridhar et al. 2010a). Bärlocher (1987) has stressed on the tolerance of some species of aquatic hyphomycetes to adverse environmental conditions. The assemblage of aquatic hyphomycetes in Kaiga stream and Kadra dam imitates other locations of the Western Ghats. Rajashekhar & Kaveriappa (2003) specified that about 10 species of aquatic hyphomycetes (*Anguillospora crassa, A. longissima, Campylospora chaetocladia, Flagellospora curvula, Helicosporium vegetum, Helicomyces roseus, Lunulospora curvula, Triscelophorus acuminatus, T. monosporus* and *Wiesneriomyces laurinus*) tolerate adverse conditions (high pH, 8.6 and above; low oxygen concentration, 4.0 mg/L and below; high iron content, 10.91–11.28 mg/L; hardwater, 170.0–204 mg/L). Among these, five species *A. longissima, F. curvula, L. curvula, T. acuminatus* and *T. monosporus* were also dominant in Kadra dam supports the observations of Rajashekhar & Kaveriappa (2003).

Altogether 28 species (range, 19–28 spp.) of aquatic hyphomycetes were recovered from natural leaves, banyan and cashew leaves assessed in two locations in three seasons in Kaiga stream and Kadra dam. The range of species is comparable to 8 out of 21 Western Ghat locations (Rajashekhar & Kaveriappa 2003). Usually the species richness and conidial output will be highest during post-monsoon in Western Ghat streams (Sridhar & Kaveriappa 1989a, Chandrashekar et al. 1990, Sridhar et al. 1992, 2010a, Raviraja et al. 1998a). For a routine survey, evaluation of water and foam may be feasible to understand the diversity and fungal assemblage. In order to follow fungal activity and colonization in a given condition, it is necessary to evaluate the immersed leaf litter in addition to natural leaf litter. A few studies monitored aquatic hyphomycetes throughout the year in Western Ghats (Chandrashekar et al. 1990, Sridhar et al. 1989a, 2010a). Variations in water qualities and input of variety of substrates influence the aquatic hyphomycetes in the Western Ghats. There seems to be no substrate specificity in aquatic hyphomycetes, but substrate preference has been found (Sridhar et al. 1992). Usually species richness will be higher in mixed leaf litter (e.g. Sridhar & Kaveriappa 1988, Chandrashekar et al. 1990; Sridhar et al. 1992) than immersed single leaf litter (Raviraja et al. 1996, 1998b). However, there are some exceptions, for instance: banyan (*Ficus benghalensis*) leaves was a preferred substrate compared to other leaf litter (e.g. banana, *Musa paradisiaca*; jack, *Artocarpus heterophyllus*) (Sridhar & Kaveriappa 1988, 1989b). In the present study, immersed banyan leaf litter showed the highest species richness (28 spp.) as well as diversity (Shannon, 4.379–4.512) of aquatic hyphomycetes compared to naturally submerged mixed leaf litter (23 spp.) and immersed cashew leaf litter (19 spp.). Some plantation leaf litter also preferred by the aquatic hyphomycetes (e.g. coffee, *Coffea arabica*; rubber, *Heavea brasiliensis*) (Sridhar & Kaveriappa 1988, Sridhar et al. 1992). In the present study, the Sorenson's similarity index between substrate and location did not show considerable variation. In the Western Ghats due to presence of mosaic of vegetation, the entry of mixed leaf litter in to the streams helps to maintain high diversity of aquatic hyphomycetes. Rajashekhar & Kaveriappa (2003) demonstrated a highly significant positive correlation between species richness of aquatic hyphomycetes with that of riparian vegetation based on their survey of 20 streams of the Western Ghats.

A few studies are available on the leaf chemistry (Raviraja et al. 1996, 1998b) and leaf enzymes (Raviraja et al. 1998b) linked with the activities of aquatic hyphomycetes in the Western Ghats. As seen in earlier studies, the present study also reveals increase in leaf nitrogen (corroborates studies by Bärlocher 1985, Webster & Benfield 1986) and decrease in leaf phosphorus and leaf phenolics. The nitrogen elevation was highest in Kaiga stream and Kadra dam during post-monsoon season coinciding with high species richness, conidial output and diversity especially in banyan leaf (see Table 3, 5). Although phosphorus in leaf litter decreased, it is the balance between leaching and immobilization by leaf microbes. The rate of leaching was high in banyan as well as cashew during post-monsoon season in both locations. But, subsequently it was steady or increased probably due to microbial immobilization. Relatively, the total phenolics lost in cashew more slowly than banyan leaves and it is reflected in low species richness as well as diversity of aquatic hyphomycetes in cashew leaves (see Table 4, 5).

Among the three enzymes studied, cellulase was higher in banyan and cashew leaves in both locations compared to xylanase and pectinase. The enzyme activity peaked within one or two weeks and subsequently remained almost steady with a few exceptions. Such increase in enzyme activity coincided with increase in total nitrogen, decrease in total phenolics and loss of leaf mass. Petersen & Cummins (1974) placed rates of decomposition of leaves based on daily decay coefficient (k) into three groups such as ‘slow’ ($k < 0.005$), ‘medium’ ($k = 0.005$-0.01) and ‘fast’ ($k > 0.01$). According to this classification, the banyan and cashew leaf litter in Kaiga stream and Kadra dam falls largely under slow decomposing category in all three seasons (k, 0.0030-0.00.0050). Relatively, decomposition of banyan leaves (k, 0.0037-0.0050) is faster in stream as well as dam compared to cashew leaves (k, 0.0030-0.0043). Decomposition of banyan and cashew leaves in Konaje (coastal) and Sampaje (Western Ghat) streams were in medium range (0.0068-0.009) (Raviraja et al. 1996). So also the banyan leaves in polluted stretch of the River Nethravathi (k, 0.0066-0.0075) (Raviraja et al. 1998b). It is evident that elevation of temperature generally increases the rate of leaf decomposition (Webster & Benfield 1986). In spite of increased water temperature in dam location compared to stream (31.1–32.4 vs. 21.1–25.6°C) the leaf decay rate was slow indicating the influence of some other factor/s. It is reflected in changes in leaf chemistry (slow decrease of organic carbon, phosphorus, phenolics and slow increase in nitrogen), low enzyme activity (xylanase and pectinase activity), low fungal diversity, species richness and spore output in dam location. Leaf mass of banyan and cashew was positively correlated with organic carbon, phosphorus and total phenolics, while negatively correlated with nitrogen and enzymes. Phenolics have been demonstrated to inhibit the fungal growth and delay in leaching will slow down the mass loss rates (Bärlocher et al. 1995), the delay in leaching of phenolics resulted in decreased mass loss in cashew leaves than banyan leaves in the present study. Negative correlation between phenolics and exoenzymes reveals that the mass loss was dependent on the quantity and extent of leaching of phenolics.

The richness, structural and functional attributes of aquatic hyphomycetes are dependent on input of organic matter, chemistry of substrates and water. Studies on aquatic hyphomycetes in the Western Ghats are biased due to assessment of water and foam and shallow water incubation of leaf litter. A few studies are available on quantification of conidial output using bubble chamber incubation. Similarly, chemistry, enzymes and mass loss of leaf litter have also been neglected. The present study showed that the difference in colonization of aquatic hyphomycetes in naturally submerged and deliberately submerged leaf litter in relation to water chemistry, leaf litter chemistry, enzymes and mass loss. Information on water chemistry and leaf litter chemistry documented in various locations of the Western Ghats will serve as baseline data. There is a need to continuously evaluate changes in the aquatic hyphomycetes population in selected streams of the Western Ghats at least for 4–5 years to understand the dominance or shift in core-group fungi, changes in fungal assemblages and pattern of succession (e.g. monsoon, post-monsoon and summer) to complement the temperate study (Bärlocher 2000).

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