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WOOD DECAY FUNGI IN HORNBILL NEST CAVITIES IN KHAO YAI NATIONAL PARK, THAILAND

Sirirak Supa-Amornkul
Department of Microbiology, Faculty of Science, Mahidol University, Bangkok, Thailand

Suthep Wiyakrutta
Department of Microbiology, Faculty of Science, Mahidol University, Bangkok, Thailand

Pilai Poonswad*
Department of Microbiology, Faculty of Science, Mahidol University, Bangkok, Thailand
*E-mail:scpps@mahidol.ac.th (*Corresponding author)*

***ABSTRACT.* –** We investigated the abundance and species diversity of wood decay fungi inside and outside cavities of predominant hornbill nest trees, *Dipterocarpus gracilis* and *Cleistocalyx nervosum* and compared with those of *Balakata baccata*, which is known as non-nest tree for lack of cavity, in a moist evergreen forest of Khao Yai National Park, Thailand. We also examined the abundance of cavities in these tree sampled from wild population. Wood samples were collected twice yearly, once in dry and the other in wet season, from inside and outside the cavities of 10 *D. gracilis* trees, 10 *C. nervosum* trees, and 6 *B. baccata* trees. Additional dead wood of *Dipterocarpus* and *Cleistocalyx* was collected in dry season to determine true wood decay fungi. A total of 1,199 fungal isolates were obtained and were classified to 68 species, 52 genera, 33 families, and 4 phyla The number of isolates was significantly higher from inside than outside the cavities and in wet season than in dry season, particularly the isolates from *Dipterocarpus* indicating wet season provides optimal condition for fungi. *Cleistocalyx* hosted the highest species richness, i.e. 51 species (75%). Forty species (58.8%) were identified from *Dipterocarpus*, and as expected the lowest was from *Balakata*, with only 16 species (23.5%). Eight species (11.8%) were found in common among all trees studied while 10, 20 and 4 species were exclusively isolated from the respective trees. Simpson's and Shannon-Weiner indices were used to determine fungal species diversity. In dry season, *Dipterocarpus* hosted the highest diversity according to Simpson's index, while *Cleistocalyx* had the lowest diversity, as demonstrated by both indices, in fungal species. Unexpectedly, wood decay fungi were dominated by soft rot fungi (91.2%) but not white rot (5.9%). The most common soft rot fungi were *Trichoderma* sp., *Gliocladium* sp. and *Fusarium* sp., and the white rot were *Coprinus* sp. and *Sporotrichum* sp. The present study suggested that wet season and enclosure condition such as inside the cavity influence the abundance and species richness. Other than moisture, additional conditions inside the cavity that may enhance the abundance and species richness of fungi included the volume of substrate (dead wood) and remaining nest debris (fruits, insects, and old feathers of imprisoned female). Further study on nature of sap and chemical compounds produced by *Balakata* is needed in order to explain the lack of large size cavity in *Balakata*, despite being a softwood tree. Nest cavities of hornbills were predominantly found in two tree genera/species, Yang sian (*Dipterocarpus gracilis*) and Wa (*Cleistocalyx nervosum*). By contrast, Sali nok (*Balakata baccata*), although it is large in size and common in the study area, no nest cavity was found. In this study, the abundance of cavities in these three tree genera was determined. The numbers of trees with at least one cavity were the lowest for *Balakata* (4%), 15.5% for *Dipterocarpus*, and 13.7% for *Cleistocalyx*. The trends were also similar for the abundance of cavities. The abundance of cavities in these tree genera was somewhat related to susceptibility of the tree to wood decay fungi. The susceptibility (or resistance) and host specificity may be related to wood structure and/or chemical substance the tree produced, which may inhibit (or enhance) growth rate of fungi and in turn affect decay process.

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***KEY WORDS.* –** Wood decay fungi, hornbill nest cavity, *Dipterocarpus gracilis*, *Clesitocalyx nervosum, Balakata baccata*, Khao Yai National Park.

INTRODUCTION

Wood decay fungi are important to ecological systems as they are responsible for recycling of plant materials and are important components of global carbon cycling (Odor et al., 2006). Their ability to degrade wood components is crucial to wood decomposition process. Three groups of wood decay fungi are recognized: white rot, brown rot and

soft rot fungi based on the components of wood that they can degrade (Käärik, 1974). Different groups have different abilities in degrading different substances. For instance, the white rot Basidiomycetes and xylariceous Ascomycetes are the principal organisms responsible for wood decay in hardwood of tropical forests. In contrast, brown rot fungi are important in coniferous forest (Hammel, 1997). Wood decay fungi utilize a variety of starting substrates, including living trees with heart and butt rot, snags or fallen logs (Lonsdale et al., 2008). Wood decay fungi thus play an important role in creating ecological niches (Lonsdale et al., 2008), including cavities in trees, and at the same time degrading dead wood of forest trees in a forest ecosystem.

How do wood decay fungi get involved in biology of hornbills, particularly in breeding biology? Hornbills are very large birds of the family Bucerotidae that inhabit tropical forest and savanna of Asia and Africa (Kemp, 1995) and are secondary-cavity nesters. They are unable to excavate their own nest cavity, and therefore strictly rely on a suitable existing cavity, which is recognized as an important breeding limiting factor (Poonswad, 1995). The role of wood decay fungi as dead wood decomposers in the forest ecosystem indirectly benefits hornbills by creating and/or enlarging a cavity, which may later serve as a nest chamber.

The availability of cavities is very important to a wide variety of animals ranging from insects, reptiles, birds to mammals, who utilize them as nesting chambers or shelters (Poonswad, 1993). In a tropical forest, a cavity in a tree can be created by a number of ways, directly or indirectly. A cavity can be actively excavated by animals, particularly birds such as woodpeckers (Family Picidae) (Hopper & Lennartz, 1991), with an assumption that eventually the cavity becomes infected by wood decay fungi and gets enlarged. The cavity can also be indirectly created in trees with physical damage caused by natural phenomena, frequently by wind. The wind breaks off branches and causes wounds on the tree trunk (Poonswad, 1995), which subsequently is subjected to infection by one or more wood-degrading microorganisms, including wood decay fungi. In a tropical forest, such as moist evergreen forest, the study of wood decay fungi is very limited (Lodge, 1997). There is no documentation on species richness inside cavities of tropical forest trees, and whether the species richness has correlation with the existence and the size of the cavity. Known information on wood decay fungi that infect tropical trees of family Dipterocarpaceae and cause heart and butt rot are fungi of genera *Ganoderma* and *Cryptoderma* (Chalermponse, 1987); and presumably a cavity is formed. Trees in family Dipterocarpaceae i.e., *Dipterocarpus*, *Hopea*, *Shorea*, *Neobalanocarpus* and *Syzygium* of Myrtaceae are known to be predominant trees, which bear nest cavities for hornbills in Thailand, (Chuailua et al., 1998, Poonswad et al., 2005). Wood of various species of *Syzygium*, on the other hand, demonstrated resistance to white and brown rot fungi tested for decay resistance in Fiji (Osboren & Lynette, 1967). Wood decay fungi do not involve only in creating cavities but also degrading cavities. This obviously has a negative effect on the hornbill. The continuation of decay process inevitably causes the cavity floor to sink deeply, thus making the cavity unsuitable as a nest for hornbills. Such cause is recognized as the main problem found in the nest trees of *Dipterocarpus* and *Syzygium* genera (Chuailua et al., 1998). The loss of suitability of a nest cavity directly affects the reproduction of hornbills and hornbill population as a whole.

In this paper, the first study in a moist evergreen forest, we investigated abundance and diversity of wood decay fungi both inside and outside cavities of hornbill nest trees. We also extended our study to investigate the wood decay fungi on non-nest trees in this forest type.

MATERIALS AND METHODS

***Study area.* –** The study was carried out in a moist evergreen forest, the habitat of hornbills, at Khao Yai National Park situated in the central-north region of Thailand (14° 15' to 14° 35'N and 101° 5' to 101° 52'E) (Fig. 1). In the park, there are four hornbill species living in sympatry, viz. Great Hornbill (*Buceros bicornis*), Wreathed Hornbill (*Rhyticeros undulatus*), White-throated Brown Hornbill (*Ptilolaemus austeni*) and Oriental Pied Hornbill (*Anthracoceros albirostris*) (Poonswad et al., 2005). Within the study area, dominant and common large trees (diameter at breast height or dbh ≥ 40 cm) are *Dipterocarpus gracilis* (referred to as *D. costatus* in Liewviriyakit, 1989), *Sloanea sigun, Castanopsis accuminatissima, Cliestocalyx nervosum* (referred to as *Eugenia* sp. in Liewviriyakit, 1989), *Choerospondias axillaris,* and *Balakata baccata* (referred to as *Sapium baccatum* in Poonswad, 1993).

***Collection of wood samples.* –** Wood samples were collected from cavities that were used by hornbills but abandoned during the study. These cavities situated in trees known as predominant nest tree species i.e., *Dipterocarpus gracilis* (Dipterocarpaceae) (referred to as *D. costatus* in Liewviriyakit, 1989) and *Cleistocalyx nervosum* (Myrtaceae) (referred to as *Eugenia cumini* in Liewviriyakit, 1989 and *Eugenia* sp. in Poonswad, 1995, and *Syzygium* sp. in Chuailua et al., 1998, Poonswad, 1995). Twenty hornbill nest cavities, ten in *D. gracilis* (*Dipterocarpus* hereafter, otherwise stated) and ten in *C. nervosum* (*Cleistocalyx* hereafter, otherwise stated), that were accessible were selected from abandoned nests with unknown cause and regardless of previous hornbill species. The mean height above ground of these cavities was 25.1±6.0 m in *Dipterocarpus* and 15.9±3.1 m in *Cleistocalyx*. To access these hornbill nest cavities, rope climbing was used. For control, wood samples were collected from six *Balakata baccata* trees (Euphorbiaceae) (*Balakata* hereafter, and referred to as *Sapium baccatum* in Poonswad, 1993), a non-hornbill nest tree species (Poonswad, 1993) with dbh ≥ 40 cm (the smallest size of tree which bears hornbill's nest, Poonswad, 1995), a common large tree species (Gardner & Sidisunthorn, 2000) at about 60 cm above ground, and an existing scar or wound on the tree trunk. Locations of studied trees were marked with GPS (Garmin, eTrex) and are shown in Fig. 1. Wood samples from all trees were collected in dry season (between December 2005 and March 2006).

In wet season, we were unable to collect samples during consecutive months due to difficulties in accessing the cavities of *Dipterocarpus*. Only wood samples from *Cleistocalyx* were collected (between June and July 2005). Wood samples from *Dipterocarpus* and *Balakata* were then collected between August and October, 2006. Additionally, wood samples from six dead *Diptercarpus* and six *Cleistocalyx* trees were collected in dry season (March 2006) for the observation of true wood rot fungi.

Wood samples were collected at various positions of the cavity using a chisel. Inside the nest cavity, samples were collected from left and right sidewalls and the wall opposite the cavity opening or nest entrance. Outside samples were collected at the backside opposite the cavity opening. From *Balakata*, samples were taken from a wound or a scar found on the trunk.

***Abundance of cavities.* –** Abundance of tree cavities with dbh ≥ 40 cm from wild populations was checked. We sampled predominant nest-tree species from 103 *Dipterocarpus* trees, 102 *Cleistocalyx* trees, and 101 non-nest *Balakata* trees along Thanarat Road inside the park between Km 31-34 posts. The number of cavities found was recorded regardless of the cavity size or position of the cavity on the tree. Measurement of individual tree size (in dbh) was not done.

***Fungal isolation.* –** Lignin cellulose medium (LCM) was modified from minimal medium (Paterson & Bridge, 1994) by adding lignin cellulose as a carbon source instead of sucrose. LCM was modified to facilitate the growth of fungi which can degrade wood components. The LCM agar was used to select wood decay fungi from wood samples. Half potato dextrose agar (1/2 PDA) was used to purify the fungal isolates. For identification of the fungi, malt extract agar (MEA), potato dextrose agar (PDA) (Merck), sabouraud 4% dextrose agar (Merck) (SDA) and sporulated medium agar (SA) (Nugent et al., 2006) were used to determine macroscopic morphology of the fungi. When molecular identification was necessary, potato dextrose broth (PDB) was used to prepare fungal mycelium.

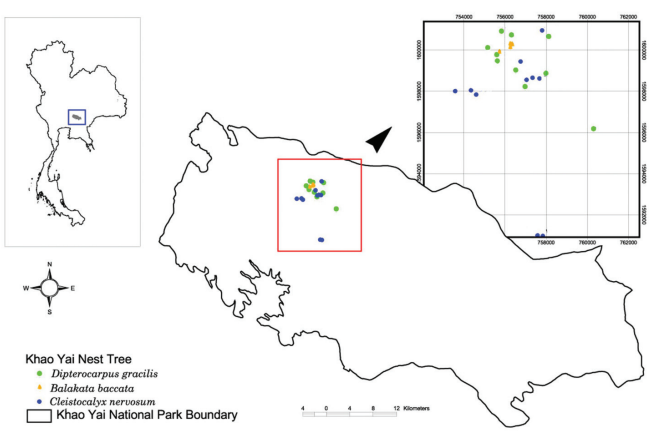


Fig. 1. Location of Khao Yai National Park and locations of sampled trees.

***Fungi identification.* –** Fungal isolates were classified to genus and species when possible. For sporulating fungi, we identified morphological characteristics through observations, both macroscopically and microscopically. For uncertain and non-sporulating fungi, molecular technique was used. Briefly, Whatman FTA card was used for extraction of fungal DNA of non-sporulating fungi. ITS1-5.8S-ITS2 regions of ribosomal DNA (rDNA) used for fungal identification were amplified by PCR using the forward primer ITS1 and the reverse primer ITS4 as described in White et al., (1990). Amplification reaction was performed in a total volume of 50 µl. Reaction mixture contained 0.5 µM of each primer, 50 µM of individual dNTP, 3 mM of $MgCl_2$, 10X buffer, 1 U Dynazyme EXT polymerase (Finnzyme) and a processed 2-mm FTA dish carrying the fungal DNA. Amplification process consisted of (i) pre-denaturation step at 95°C for 3 min, (ii) 30 consecutive cycles at 95°C for 50 sec (denaturation), 55°C for 40 sec (annealing) and 72°C for 40 sec (extension), and (iii) a final extension at 72°C for 10 min. PCR products were ligated into pGEM-T easy vectors for preparation of recombinant plasmids and transformed into *E. coli* DH5α. Isolated plasmid from each clone was checked for insertion by restriction enzyme digestion. Extracted plasmids were sequenced in an automate sequencer (ABI PRISM ™ model 3730XL, Perkin Elmer). The fungi were identified by comparing the ITS1-5.8S-ITS2 sequences with those of the reference strain fungi in the GenBank.

***Data analyses.* –** To compare the abundance of cavities found in *Dipterocarpus, Cleistocalyx* and *Balakata* trees, Chi square-test was used. The fungal species richness isolated from each studied tree species was compared by rarefraction method. To measure diversity of isolated fungi, the Simpson's reciprocal and Shannon-Wiener indices were used. To test the correlation between the numbers of isolates and species, Spearman Rank Correlation was used. To determine similarity of isolated fungi in various host trees, Chao-Sorensen Est-Abundance Base was applied (Chao et al., 2005). Species richness and diversity indices were calculated by BioEdit version 7.0. All statistic tests were calculated by SPSS version 13.00 program.

RESULTS

***Abundance of cavities in studied trees.* –** The numbers of cavities found in wild tree population were relatively low, only 34 (11.1%) out of 306 trees (Table 1). There was no difference in the numbers of cavities recorded from *Dipterocarpus* and from *Cleistocalyx* trees, (χ^2=0.668, df=1, *P*=0.414) (Table 1). *Balakata*, as non-nest trees, obviously had a low number of cavities. Therefore, *Balakata* had significantly less cavities than those of the former two species (χ^2=9.78, df=1, *P*=0.02 and χ^2=6.093, df =1, *P*=0.014, respectively). The number of cavities per tree was highest in *Cleistocalyx* (1.8 cavities /tree) (Table 1). It was also noticed that cavities found in *Balakata* were shallow and small.

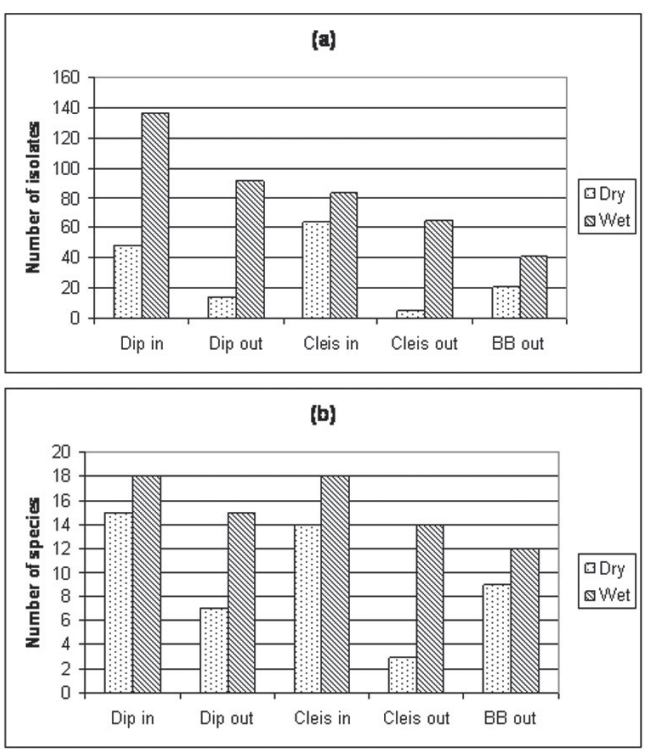
***Fungal abundance and seasonality.* –** A total of 1,199 fungal isolates were obtained from studied trees and two additional

Table 1. Number of cavity trees and average number of cavities observed in sampled trees from wild populations of *Dipterocarpus, Cleistocalyx*, *Balakata* at Khao Yai National Park.

Tree species	N	No. cavity tree (%)	Total cavity	Ave. number of cavities per tree
Diptercarpus	103	16 (15.5)	17	1.1
Cleistocalyx	102	14 (13.7)	25	1.8
Balakata	101	4 (4.0)	4	1
Total	306	34 (11.1)	46	

dead *Dipterocarpus* and *Cleistocalyx* (Table 2). Of the total, the number of isolates obtained from *Dipterocarpus* and *Cleistocalyx* in both wet and dry seasons were similarly high, 565 isolates (47.1%) and 513 (42.8%), respectively (Table 2). However, the highest number of isolates (429 isolates) was from the cavities of *Dipterocarpus* in wet season. To compare the total number of isolates from these nest trees and that from *Balakata*, we also included the isolates from outside the cavity. In wet season, the number of isolates was apparently higher than that in dry season for all studied trees (Table 2, Fig. 2a, and Appendices 1a–b). Distinct increase in the number of isolates in wet season indicated that season has high influence on the abundance of fungi, especially on *Dipterocarpus* and *Cleistocalyx* (Appendices 1a–b).

The majority of isolates, 1,182 (98.6%), sporulated in cultures, and 90.9% (1,074 isolates) were from *Dipterocarpus* and *Cleistocalyx*. The rest (17 isolates, 1.4%) were non-sporulating fungi and were mainly from *Balakata* in wet season (10 isolates, 58.8 %) (Table 2).



Dip in = fungi from inside cavity of *Dipterocarpus*, Dip out = fungi from outside cavity of *Dipterocarpus*, Cleis in = fungi from inside cavity of *Cleistocalyx*, Cleis out = fungi from outside cavity *Cleistocalyx*

Fig. 2. a) Total number of fungal isolates from 10 of studied trees in different seasons and b) Total number of fungal species isolated from studied trees in different seasons.

To compare the average number of isolates from inside and outside the cavity, we consistently calculated the number of isolates from samples collected from one location, the right wall of the cavity, since the average numbers of isolates obtained from various locations inside the cavity showed no significant difference. Therefore, the data shown in Table 3 and Fig. 2 were from the right wall inside the cavity. For the rest of the analyses, we used entire data from all samples collected inside and outside (Appendices 1a–b), otherwise stated. Fig. 2a compares total number of fungal isolates obtained from inside and outside the cavities of *Dipterocarpus*, *Cleistocalyx* and *Balakata* in dry and wet seasons. The average number of fungal isolates collected from inside and outside cavities among these studied trees in both seasons were significantly different (Kruskal-Wallis test, χ^2=54.756, df=3, P=0.000) (Table 3). The average number of isolates was the highest, both from inside and outside cavity of *Dipterocarpus*, in wet season and significantly differed from those of *Cleistocalyx.* Overall, pairwise test shows significant difference between the average numbers of isolates from inside and outside in both seasons, except for a few pairs (Table 3). It is apparent that wet season and location (i.e., inside the cavity) had influence on the abundance of fungi (Table 3 and Fig. 2a). The isolate abundance was found to be very highly correlated with the number of species (Spearman Rank Correlation: R^2 0.900, P=0.000, N=52) (Fig. 2). Therefore, both terms, isolates and species, were used in the following analyses**.** Species richness had the same trend as the abundance of isolates i.e., high in wet season and from inside the cavities (Table 2, Fig. 2b, and Appendices 1a–b).

***Species richness, diversity and composition.* –** The species accumulation curves for species richness of fungi isolated from different studied tree species shows that species added per tree appeared to reach or nearly reach stationary state for all host tree species (Fig. 3a). Similar trend, species accumulation curves obtained from outside the cavity or on the trunk of each studied trees nearly reached stationary state except for those of *Balakata* (Fig. 3b). The highest number of species was recorded from *Cleistocalyx* trees (Table 2, Fig. 3, and Appendix 1a). However, additional number of trees to each host tree/wood may yield a slightly more genera/species. Hence, number of sample size used in this study was considerably sufficient.

List of fungal isolates and species recorded from inside and outside of all studied trees and wood in dry and wet seasons is given in Appendix 1. Of the 1,199 isolates, there were 68 species (43 unidentified) of 52 genera from 30 families in 4 phyla identified (Table 2 and Appendix 1a). Among the

Table 2. Summary of fungal isolates identified in this study. Shown here are the numbers of isolates, total genera/species, sporulating and non-sporulating fungi, the number of classified fungi, and diversity indices and evenness by season for each studies tree.

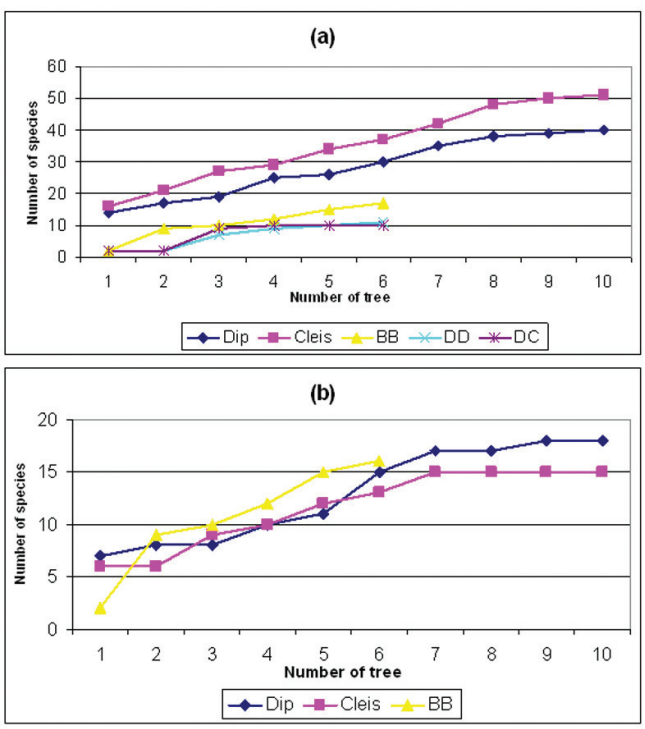
	Dry					Wet				Both seasons		
	Dip (n=10)	**Cleis (n=10)**	**BB (n=6)**	**Dead Dip (n=6)**	**Dead Cleis (n=6)**	**Dip (n=10)**	**Cleis (n=10)**	**BB (n=6)**	**Total**	**Dip (n=20)**	**Cleis (n=20)**	**BB (n=12)**
Total (Isolates)	**136**	**195**	**21**	**22**	**37**	**429**	**318**	**41**	**1199**	**565**	**513**	**62**
Total (Genera/Species)	**23**	**27**	**9**	**11**	**10**	**33**	**40**	**12**	**68**	**40**	**51**	**16**
Sporulating												
Species	23	27	9	10	10	32	37	10	62			
Genera	16	20	8	7	4	22	26	7	45			
Family	9	11	4	4	4	14	19	8	28			
Phylum	3	3	2	2	1	4	4	1	4			
uncertain	0	1	0	0	0	0	1	0	2			
Total (isolates)	136	195	19	21	37	428	315	31	1182			
Non-sporulating												
Species	0	0	1	1	0	1	3	2	6			
Genera	0	0	1	1	0	1	3	2	6			
Family	0	0	1	1	0	1	3	2	5			
Phylum	0	0	1	1	0	1	1	1	2			
Uncertain	0	0	0	0	0	0	0	0	0			
Total (isolates)	0	0	2	1	0	1	3	10	17			
Inside and outside cavity												
Simpson's index	10.30	6.35				7.52	9.02					
Shannon-Weiner index	1.14	1.02				1.06	1.21					
Outside cavity												
Simpson's index	11.34	3.33	10.50	8.56	4.47	5.94	6.30	9.21				
Shannon-Weiner index	0.83	0.41	0.905	0.93	0.77	0.91	0.91	0.97				

Dip = *Dipterocarpus*, Cleis =*Cleistocalyx*, BB=*Balakata*, Dead Dip=sampled from *dead Dipterocarus* wood, Dead Cleis=sampled from *dead Cleistocalyx* wood.

68 species, 40 species (58.8% of total) were identified from *Dipterocarpus*, 51 (73.5%) from *Cleistocalyx*, 16 (23.5%) from *Balakata*, 11 (16.2%) from dead *Dipterocarpus* and 10 (14.7%) from dead *Cleistocalyx*. There were 10 exclusive species (14.7%) found in *Dipterocarpus*, 20 (29.4%) in *Cleistocalyx*, four species (5.9%) in *Balakata*, and only one species (1.5%) i.e., *Trichoderma spirale* in dead *Dipterocarpus*. There were eight species (11.8%) found in common among these three studied species (Table 2 and Appendix 1a). Among 30 exclusive species found in both species of nest trees, there were 23 species (76.7%) found only inside the cavity and four species (13.3%) found outside the cavity regardless of host tree species (Appendix 1b).

There were three unidentified species of *Fusarium*, *Gliocladium* and *Trichoderma* genera found in most abundance in both seasons (Appendix 1a). Of 68 species obtained, 14 (20.6%) were isolated only once. Five isolates could not be identified to species level (Appendix 1a).

Considering diversity indices given in Table 2, we compared between *Dipterocarpus* and *Cleistocalyx* based on the same data collection from both inside and outside the cavities. The highest diversity was from *Dipterocarpus* in dry season determined by both Simpson's and Shannon-Weiner indices (10.30 and 1.14, respectively). In contrast, fungal diversity in *Cleistocalyx* was markedly high in wet season, (9.02 and 1.21, respectively) (Table 2). To compare species diversity index among 3 studied tree species, we used data from outside the cavity. *Dipterocarpus* hosted highest species diversity of



Dip = sample from *Dipterocarpus*, Cleis = sample from *Cleistocalyx*, BB = sample from *Balakata*, DD = dead *Dipterocarpus*, DC = dead *Cleistocalyx*

Fig. 3. a) Species accumulation curves obtained from each type of studied tree species/wood and b) species accumulation curves obtained from outside-cavity or tree- trunk isolates for each type of studied tree species/wood.

wood decay fungi in dry season (Simpson's index: 11.34), but the diversity markedly decreased in wet season based on Simpson's index. In contrast, species diversity in *Cleistocalyx* was the lowest in dry season, indicated by both Simpson's and Shannon-Weiner indices (3.33 and 0.44, respectively) and increased drastically (6.30 and 0.91, respectively) in wet season. On the other hand, species diversity in *Balakata* was similar in both seasons. It should also be noted that the dead *Cleistocalyx* hosted low fungal diversity as confirmed by both values of Simpson's and Shannon-Weiner indices (4.47 and 0.77, respectively).

The ten most common fungal species ranked by the number of isolates from each studied tree genus and dead wood are shown in Table 4 and accounted for a total of 25 species from five different sample types (trees and wood). Scoring was obtained from ranking of fungal species by host trees. The rank of each fungal species from each tree/wood was scored ranging from 10 to 1 for corresponding rank 1 to 10, then combined to get final rank for each fungal species. *Trichoderma* sp. 1 was the most frequently isolated in this study, followed by *Gliocladium* sp. 1 and *Fusarium* sp. 1 (Table 4).

Wood decay fungi found in this study were dominated by soft rot fungi (62 species, 91.2% of the total 68) (Table 5). Among these soft rot fungi, 58 of 62 species (93.5%) were in Ascomycota (Appendix 1a). There were only two species of white rot fungi i.e., *Coprinus* sp. isolated only from outside of *Dipterocarpus*, and *Sporotrichum* sp. isolated from both inside and outside cavities of both *Dipterocarpus* and *Cleistocalyx* (Table 5 and Appendix 1a). Soft rot fungi were isolated in all studied trees with similar percentages (Table 5). While white rot fungi were isolated from cavities of *Dipterocarpus* and *Cleistocalyx*, but not from *Balakata*. *Candelariella* sp., *Candida* sp., *Carpoligana* sp., and *Phaetrichospaeria* sp. were not wood decay fungi (Table 5 and Appendix 1).

DISCUSSION

***Fungal abundance and species richness.* –** Among limited studies on wood decay fungi in tropical forest, most of wood documented decomposition by wood decay fungi (Lonsdale et al., 2008; Osboren & Lynette, 1967; Setala & MacLean, 2004) and host specificity (Gilbert & Sousa, 2002, May, 1991), but not the species richness of wood decay fungi from tree cavities. More numbers of fungal isolates and species richness in wet season than in dry season for all sample trees in this study (Tables 2–3; Fig. 2a–b; Appendix 1) indicate the influence of physical environment factors on the growth of fungi, which appears to be in agreement with Käärik (1974) who suggested that the most important factors in spreading and survivals of microorganisms in wood are moisture content of the wood, aeration, temperature and interaction between microorganisms. Being a suitable host for any microorganisms, there is one important process i.e., establishment. The establishment of wood decay fungi is known to dependent on combined factors, including infection source (e.g., arrival of spores), optimal physical

Table 3. Mean isolates of fungi collected from inside and outside cavities of *Dipterocarpus* and *Cleistocalyx* in both seasons with χ^2 and *z* – values.

Tree	Inside cavity		Outside cavity		Kruskal-Wallis test		Wilcoxon	Signed Rank test	Mann – Whitney U- test	
	Dry	Wet	Dry	Wet	χ^2 (df=3)	*P*	Z	pair	Z	pair
Dip							-2.710	DDI&DDO*	-1.338	DDI&DCI
Mean	4.8	13.6	1.4	9.1			-2.652	DCI&DCO*	-0.472	DDO&DCO
S.D.	1.5	2.8	2.1	2.8			-2.814	WDI&WDO*	-2.576	DDO&DBO*
Range	3 - 7	9 - 19	0 - 5	5 – 14			-2.668	WCI&WCO*	-3.038	DCO&DBO*
N	10	10	10	10						
Cleis							-2.812	DDI&WDI*	-2.898	WDI&WCI*
Mean	6.4	8.3	0.5	6.3			-2.812	DDO&WDO*	-2.552	WDO&WCO*
S.D.	3.6	4.0	0.7	3.9	54.756	0.000	-1.127	DCI&WCI	-1.988	WDO&WBO*
Range	0 - 11	2 - 16	0 - 2	1 – 14			-2.677	DCO&WCO*	-2.137	WCO&WBO*
N	10	10	10	10						
BB							-1.682	DBO&WBO		
Mean			3.5	6.8						
S.D.			1.6	3.6						
Range			1 – 5	0 – 10						
N			6	6						

Dip=*Dipterocarpus,* Cleis=*Cleistocalyx*, BB=*Balakata,* DDI=isolates from *Dipterocarpus* inside cavity in dry season, DDO=isolates from *Dipterocarpus* outside cavity in dry season, DCI=isolates from *Clesitocalyx* inside cavity in dry season, DCO=isolates from *Cleistocalyx* outside cavity in dry season, DBO=isolates from *Balakata* in dry season, WDI=isolates from *Dipterocarpus* inside cavity in wet season, WDO=isolates from *Dipterocarpus* outside cavity in wet season, WCI=isolates from *Clesitocalyx* inside cavity in wet season, WCO=isolates from *Cleistocalyx* outside cavity in wet season, WBO =isolates from *Balakata* in wet season, *= significantly different ($P < 0.05$).

Table 4. The ten most prevalent genera/species recorded from each studied tree and dead wood with sum scores and final ranks.

Species	Rank					Sum Score	Final Rank
	Dip	Cleis	BB	DD	DC		
Trichoderma sp1.	2	1	1	1	1	49	1
Gliocladium sp1.	1	4	5	6	4	35	2
Fusarium sp1.	5	2	6	6	2	34	3
Gliocladium virens	3	3			6	21	4
Fusarium solani	8	8		3	6	19	5
Fusarium ventricosum	6	5			5	17	6
Trichoderma harzianum				2	3	17	6
Sporotrichum sp.	3	6				13	8
Paecilomyces victoriae	3	6				13	8
Aspergillus sp.	9		4			9	10
Bipolaris oryzae			2			9	10
Cylindrocarpon sp.		7		6		9	10
Mucor sp.				3		8	13
Penicillium sp.				3		8	13
Acremonium sp.		8			6	8	13
Phialophora richardsiae					6	5	16
Trichoderma spirale				6		5	16
Paecilomyces sp.				6		5	16
Pythium sp.	7					4	19
Mortierella sp.			7			4	19
Arthrographis cuboidea			8			3	21
Codinaea sp.			8			3	21
Carpoligna sp.			8			3	21
Verticillium sp.	10					1	24
Cylindrocladium sp.		10				1	24

The lowest value of the rank is genus/species which has the highest number of fungal isolates.
Dead=dead *Dipterocarpus* and *Cleistocalyx* wood sample.

Table 5. Numbers of genera/species and percentages of each wood decay fungal group found in studied trees and dead wood.

Fungal group	*Dipterocarpus*		*Cleistocalyx*		*Balakata*		Dead Dip		Dead Cleis		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	
Soft rot	36	90	48	94.1	15	93.8	11	100	10	100	62
White rot	2	5	1	2	0	0	0	0	0	0	4
Non rot	2	5	2	3.9	1	6.2	0	0	0	0	2
Total genera/species	40		51		16		11		10		68

Dead Dip=dead *Dipterocarpus* wood, Dead Cleis=dead *CLeistocalyx* wood.

environment conditions (e.g., temperature and moisture), suitable substrate, and absence of poisonous or inhibiting substances (Käärik, 1974). Not only external factors or physical factors are important, the establishment is certainly influenced by biological factors, for instance, plant cell components, which form wood structure and properties. Cell walls of these have different structures which resist to different fungal enzymes (Akin et al., 1995; Gilbert & Sousa, 2002) at different levels.

This study strongly suggests that an important external factor for growth of fungi is moisture. Fungal species richness in the studied trees during wet season and inside the cavity (Tables 2–3; Fig. 2; Appendix 1) clearly favors moist condition. Inside the cavity, moisture may not differ much in both dry and wet seasons. Thus, species richness in both *Dipterocarpus* and *Cleistocalyx* was relatively similar, except for inside *Cleistocalyx* in wet season which accommodated the highest species richness (Fig. 2b; Appendix 1b). Relative humidity inside a hornbill nest cavity measured 24 hours varied between 70% and 100% and daily mean temperature varied between 22°C and 27°C in dry season and in the same area as the present study (Poonswad, 1993). These ranges of environmental factors are perhaps suitable for the

establishment and growth of the fungi. On the other hand, daily relative humidity on the ground varied greatly between 40% and 100% and mean temperature varied between 19°C and 23.3°C in dry season (Poonswad, 1993). This may not favor the growth of fungi outside the cavity as shown by pairwise test (Table 3). The number of fungal isolates from *Balakata* (only outside) did not differ in both seasons but was significantly less than those of the other two species in both seasons. This moisture content does not correspond to the case of *Balakata*. If the decay rate is related to the ability of fungi to establish, which may further be implied to species richness, then the effect of wood moisture content on decay rate documented by Käärik (1974) would be sensible. As wood of *Balakata* contains very high moisture content (187%, Appendix 2); therefore, it may inhibit the establishment of the fungi. Besides high moisture content, this case suggests that there might be other factors which reduce the susceptibility or establishment. For instance, sap and chemical compounds produced by this tree may have defensive properties or activities which prevent further infection after an injury occurs (e.g., after sample collection in the first season). Therefore, it is interesting to study fungi inside those small and shallow cavities of *Balakata* and nature of its sap, particularly chemical compounds produced and their activities.

Other than moisture and temperature, factors influencing species richness inside the cavity include physical environments and nest debris (e.g. fruits and insect remains). It is known that imprisoned female and chicks are fed with a great variety of fruits and insects by the male (Poonswad et al., 1998). These debris and remains provide optimal condition and additional substrates for fruit rot fungi. High species richness inside the cavities of *Dipterocarpus* and *Cleistocalyx* may be influenced by these fungi living on such debris inside the cavity. High number of isolates in *Dipterocarpus* was greatly contributed by the isolates of *Gliocladium* sp., which is one of the documented fruit rot fungi (Appendix 1a).

***Wood decay fungi and cavities.* –** In this study, the initiation of a cavity in these studied trees is not our prime objective. For hornbills, as secondary cavity nesters, are unable to excavate their own nests (Poonswad et al., 1987). Cavities in trees speculated to be the results of interactions between wood of host tree (substrate) and decomposers, including wood decay fungi, after the trees have been injured by any causes. There are a number of studies suggesting that the rate of wood decomposition by the complex of wood-colonizing microorganisms, including wood decay fungi, tends to be affected by seasonal variations of temperature and moisture content in wood (Käärik, 1974; Lonsdale et al., 2008; Poonswad, 1995). Wood decay fungi play important roles in hornbill's life through decomposition process: positive effect (e.g., creation of a cavity) and negative effect (e.g., degrading a nest chamber). Being predominant nest tree species, the *Dipterocarpus* and *Cleistocalyx* and the non-nest tree, the *Balakata*, were confirmed by the corresponding number of cavities recorded in wild population and the abundance of wood decay fungi isolated (Tables 1, 2, 5, Fig. 2b and Appendix 1).

Study on the relationship between species richness and decomposition rate is inconclusive. However, there are studies on species richness of soil fungi that had positive relationship with litter decomposition rate (Setala & MacLean, 2004; Tiunov & Scheu, 2005). Käärik (1974) documented that wood with moisture content between 60 and 100 % would be rapidly decomposed, and those contains moisture lower than 30% or higher than 120% would not be putrefied. If consider only wood moisture content, only a few and small cavities would have been expected from *Cleistocalyx* and *Dipterocarpus*. While *Cleistocalyx* had highest number of cavities and highest species richness of wood decay fungi (Tables 1–2), wood of this species contains 12 % of moisture content, which is the same as *Dipterocarpus* (Appendix 2). We hypothesize that toughness and strength of wood affect fungi susceptibility and decay rate, as observed in the tree with tougher wood i.e., *Dipterocarpus*, which has reduced fungi susceptibility and decreased decay rate, when compared to *Cleistocalyx* (Appendix 2). On the contrary, *Balakata* wood properties (including toughness, strength and hardness) are far less than those of the former two species, except for the very high moisture content (187%). However, *Balakata* wood had the least number of cavities and the lowest species richness. Other evidence, which may better explain the difference in fungal species richness, by Lonsdale et al. (2008) stated that species richness of wood decay fungi positively related with the amount of substrate. Therefore, the substantial differences in fungal species richness between those of *Cleistocalyx* or *Dipterocarpus* and *Balakata* can be explained by the fact that the former two species had greater volume of substrates (dead wood) inside the cavity but lack in the latter species.

However, studies on wood decay fungi and their host trees suggest that structure of plant cells and antifungal components in each plant species influence decay process by wood decay fungi (Akin et al., 1995; Alfredsen et al., 2008; Gilbert & Sousa, 2002). Major components of wood cell wall are cellulose, hemicelluloses, and lignin. Wood decay fungi of different groups have different ability in breaking down these substrates (Käärik, 1974). Lacking information on wood cell wall components of all trees in this study, it is not possible to make a conclusion that wood components are involved as factors in wood degradation by wood decay fungi. The highest species richness of wood decay fungi isolated from inside cavities of *Cleistocalyx* trees in this study (Tables 2, 5, Fig. 2b and Appendix 1b) and higher percentage of nest cavities with sunken floor in *Cleistocalyx* than those in *Dipterocarpus* (Chuailua et al., 1998) may imply that the rate of wood decomposition inside the cavity of *Cleistocalyx* is higher than that of the *Dipterocarpus* trees, which hosted less species richness (Tables 2 and 5, Fig. 2b). As availability of suitable nests is important for hornbill population, wood decay results in relatively high percentage of cavity loss, which directly affects hornbill breeding. The sunken nest floor, as a result of decomposition process, in these two predominant nest trees may be enhanced by relative humidity and temperature inside the cavity (70–100% and 22–27°C, respectively, Poonswad, 1993), although the wood of these two species has low moisture content.

Wood decay fungi isolated in this study were dominated by soft rot fungi (62 species or 91.2% of total species, Table 5). This composition is similar to the fungi found in woodpecker nest-cavity trees or snags, which are predominated by filamentous Deuteromycetes fungi and yeast (Huss et al., 2002). There were only two species of white rot fungi, *Coprinus* sp. and *Sporotrichum* spp., and, as expected, none of brown rot fungi. The establishment of soft rot fungi may be influenced by the following factors. Firstly, the physical conditions inside the cavity may favor soft rot fungi. For instance, relative humidity inside the cavity tends to be higher than that of the outside (Poonswad, 1993), and the soft rot fungi tend to be found under high moisture conditions (Käärik, 1974). Secondly, after the pioneer species invades a wound of a tree, it normally causes heart and butt rot resulting in cavity formation. Then appropriate conditions in the cavity would facilitate the succession of other fungi. Thirdly, the succession of soft rot fungi appears to overwhelm the other groups of fungi. It could be that the cavities in this study were old (indicated by its large size, which accommodates a female hornbill and one chick or more), and that succession of the fungal community in the cavities has already occurred. Fourthly, either mutual or antagonistic interaction among fungi may affect the growth of one another on the host. Many soft rot fungi (e.g., *Trichoderma* spp*., Penicillium* spp*., Gliocladium* spp*., Aspergilus* spp.) established in this study were known to be antagonistic to the growth of Basidiomycetes (Ejechi, 1997, Huss et al., 2002). Therefore, the appearance of certain species of wood decay fungi is directly related to the time length and the decay rate.

Succession of fungi can take over the pioneer species through a series of organisms, which are capable of utilizing various components of wood as substrates over the course of time (Huss et al., 2002). From this information, it is clear that along the steps of wood degradation, different types of microorganisms are involved. Hence, rough dating of a cavity existence may be possible. Most of the fungi in this study which are known to have antagonistic activity to other fungi were predominantly found inside the cavities of *Dipterocarpus* and *Cleistocalyx.* This may be another reason the only one species of white rot fungi, *Sporotrichum* sp., was found in wood samples collected from inside nest cavities, whereas *Coprinus* sp. was only isolated from outside the cavity of *Dipterocarpus* in wet season. The establishment of *Coprinus* sp. in wet season can be interpreted as either this species is specific to *Dipterocarpus* tree or it is a seasonal occurrence. The positions where wood samples were collected from outside of the cavities of *Dipterocarpus*, *Cleistocalyx*, and *Balakata* in dry and wet seasons were relatively in the same region. This implies that a wound was first created in dry season and then wood sample collections were repeated in wet season. Then, *Coprinus*, which was one of the pioneer species that created a cavity, may establish on *Dipterocarpus* tree during wet season.

***Species diversity and host specificity.* –** Two diversity indices adopted in this study in order to measure the diversity of fungal community on different host tree species weight on different factors. Simpson's index is the highest for fungal diversity of *Dipterocarpus* tree and second by that of *Balakata* (Table 2), while Shannon-Weiner index is the highest for fungal diversity of *Balakata*. Simpson's index weighs towards equitability and is an intrinsic diversity index, giving the probability of any two individuals belonging to different species. Shannon-Wiener index is used in statistics as a diversity index. It is notoriously sample-size dependent and tends to be weighted slightly towards species richness. The result of this study corresponds to principle concept of these two indices. *Balakata* had the second highest diversity of fungi and its isolate number per species was evenly distributed, which was also indicated by the highest evenness value (Table 2). Whereas *Cleistocalyx* had markedly the lowest species diversity in dry season, and the number of isolates per species did not evenly distribute as it was indicated by the lowest evenness value (Table 2). In order to obtain accurate measurement of diversity, it is necessary to use more than one diversity index.

It is not possible to determine the host specificity of fungi in this study due to inadequate samples of tree species studied, but we can present the exclusive species and wide host range species found under these limiting conditions. From the total of 68 fungal species found in this study, 35 species (51.5% of total) were exclusively found in all studied tree species (Appendix 1a). Among these fungi found from each studied tree, *Cleistocalyx* had the highest exclusive species (20 species or 29.4%, Appendix 1) indicating *Cleistocalyx* as a good host for many wood decay fungi. On the other hand, there were a few fungi (eight species or 11.8 % of total) that had wide host range (*Dipterocarpus, Cleistocalyx* and *Balakata*). About one third of the total species shared host trees of *Dipterocarpus* and *Cleistocalyx* (Appendix 1a). This may be one of the reasons these two tree species have similar numbers of cavities. Polishook (1996) suggested that much of host preference exhibited by micro-fungal decomposers may relate to physical and chemical characteristic factors rather than host specificity by the sole taxonomic sense. Wood of some species have anti-fungal substances which resist certain species of fungi (Alfredsen et al., 2008) and this may result in different fungal community establishing in different wood.

On the other hand, May (1991) have reported that the high diversity in tropical forest ecosystems may better support those low host-specificity fungi than those in low-diversity forests. It is further commented that the low density of individual host species in high-diversity forests limits the host preference or fungal population growth on suitable substrates (May, 1991). The exclusive fungi in *Dipterocarpus* and *Cleistocalyx* were found more in wet season. This clearly demonstrates the influence of the environmental factors rather than specific tree genera. From this study, it was inconclusive whether the exclusive fungi found on *Dipterocarpus* and *Cleistocalyx* were genuine host specific ones because they were from too small number of host tree species and from too few numbers of isolates (Appendix 1).

Overall, the total of 68 species found in this study tended to yield the maximum number of species richness of wood

decay fungi obtained from adequate number of host trees from each species (Fig. 3). To lengthen the species list, one should include more host tree species. Regardless of evenness, *Cleistocalyx* had greatest diversity of fungal species, whereas *Balakata* had the lowest. This substantial difference in establishment of fungi between *Cleistocalyx* and *Balakata* (Tables 2 and 3) tends to be affected by a number of combined factors, such as season and condition inside the cavity (e.g., temperature, aeration, humidity and substrate). The latter was not available in *Balakata*. Besides physical and biological (i.e., wood properties) factors, chemical compounds in wood may limit the growth of certain species. Wood of some species has anti-fungal substance, which resists certain species of fungi (Alfredsen et al., 2008) and results in different fungal community establishing in different wood.

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Appendix 1.
a) Type of wood decay fungi, genus/species of fungi and numbers of isolates from *Dipterocarpus, Cleistocalyx, Balakata*, dead *Dipterocarpus* and dead *Cleistocalyx* by season.

	Classification				**Dry**				**Wet**		**Total**	**%**
Phylum **Type** of rot fungi		**Genera/Species**	**Dip**	**Cleis**	**BB**	**DD**	**DC**	**Dip**	**Cleis**	**BB**	**Iso**	**Iso**
Ascomycota												
	Bionectriaceae											
Soft rot		*Gliocladium roseum*	1	0	0	0	0	0	0	0	1	0.08
	Candelariaceae											
Non trot		*Candelariella* sp.	1	0	0	0	0	1	0	0	2	0.17
	Capnodiales										0	0
Soft rot		*Fumago* sp.	0	0	0	0	0	0	3	0	3	0.25
	Chaetomiaceae											
Soft rot		*Achaetomium* sp.	0	0	0	0	0	0	2	0	2	0.17
Soft rot		*Chaetomium* sp.	0	0	0	0	0	0	1	0	1	0.08
	Chaetosphaeriaceae											
Non rot		*Carpoligna* sp.	0	0	0	0	0	0	0	2	2	0.17
Soft rot		*Codinaea* sp.	0	0	0	0	0	0	2	2	4	0.33
	Dipodascaceae											
Soft rot		*Dipodascus* sp.	0	2	0	0	0	0	0	0	2	0.17
Soft rot		*Galactomyces geotrichum*	0	0	0	0	0	0	1	0	1	0.08
	Hypocreaceae											
Soft rot		*Acremonium* sp.	3	8	1	0	1	2	3	0	18	1.5
Soft rot		*Cylindrocladium* sp.	2	3	0	0	0	4	6	0	15	1.25
Soft rot		*Fusarium ciliatum*	0	1	0	0	0	0	0	0	1	0.08
Soft rot		*sarium solani*	5	4	0	2	1	14	7	0	33	2.75
Soft rot		*Fusarium roseum*	1	0	0	0	0	0	0	0	1	0.08
Soft rot		*Fusarium* sp1.	11	49	2	1	6	25	31	2	127	10.59
Soft rot		*Gliocladium virens*	2	9	0	1	1	41	43	2	99	8.26
Soft rot		*Gliocladium viride*	0	0	0	0	0	2	0	0	2	0.17
Soft rot		*Gliocladium* sp1.	24	25	5	1	3	100	22	0	180	15.01
Soft rot		*Trichoderma hamatum*	0	0	0	0	0	2	2	0	4	0.33
Soft rot		*Trichoderma harzianum*	1	0	0	3	5	2	0	1	12	1
Soft rot		*Trichoderma koningi*	0	0	0	0	0	1	1	0	2	0.17
Soft rot		*Trichoderma spirale*	0	0	0	1	0	0	0	0	1	0.08
Soft rot		*Trichoderma* sp1.	26	53	3	7	16	96	85	8	294	24.52
Soft rot		*Verticillium* sp.	3	4	0	0	0	9	5	0	21	1.75
	Microascaceae											
Soft rot		*Microascus* sp.	0	0	0	0	0	0	3	0	3	0.25
	Mitosporic Ascomycota											
Soft rot		*Gliomastix* sp.	0	1	0	0	0	1	0	0	2	0.17
Soft rot		*Humicola* sp.	4	1	0	0	0	2	0	0	7	0.58
Soft rot		*Papulaspora* sp.	0	0	0	0	0	1	1	0	2	0.17
Soft rot		*Phoma* sp.	0	0	0	0	0	0	2	0	2	0.17

Appendix 1. Cont'd

Phylum / Type of rot fungi	Classification	Genera/Species	Dry					Wet			Total	%
			Dip	Cleis	BB	DD	DC	Dip	Cleis	BB	Iso	Iso
Soft rot		*Trichocladium* sp.	3	0	0	0	0	0	0	0	3	0.25
Ascomycota												
	Mitosporic Calosphaeriaceae											
Soft rot		*Phialophora richardsiae*	0	3	0	0	1	0	1	0	5	0.42
	Mitosporic Dermateaceae											
Soft rot		*Trichosporiella* sp.	0	4	1	0	0	0	0	0	5	0.42
	Mitosporic Eremomycetaceae											
Soft rot		*Arthrographis cuboidea*	0	0	0	0	0	0	0	2	2	0.17
	Mitosporic Leptoshaeriaceae									0	0	
Soft rot		*Epicoccum* sp.	0	0	0	0	0	0	1	0	1	0.08
Soft rot		*Coniothyrium* sp.	0	0	0	0	0	4	0	0	4	0.33
	Mitosporic Magnaporthaceae											
Soft rot		*Phialophora* sp.	0	0	0	0	0	2	0	0	2	0.17
	Mitosporic Microascaceae											
Soft rot		*Graphium putredinis*	0	0	0	0	0	2	5	0	7	0.58
Soft rot		*Graphium* sp.	0	0	0	0	0	0	2	0	2	0.17
	Mitosporic Pezizaceae											
Soft rot		*Oedocephalum* sp.	0	0	0	0	0	0	1	0	1	0.08
	Mitosporic Pezizomycotina											
Soft rot		*Torula herbarum*	0	0	0	0	0	0	1	0	1	0.08
Soft rot		*Torula* sp.	3	0	0	0	0	0	0	0	3	0.25
	Mitosporic Trichocomaceae											
Soft rot		*Paecilomyces victoriae*	0	0	0	0	1	0	0	7	8	0.67
Soft rot		*Paecilomyces* sp.	4	1	0	1	0	2	0	0	8	0.67
Soft rot		*Penicillium* sp.	10	4	2	2	0	0	1	0	19	1.58
Soft rot		*Aspergillus parasiticus*	0	0	0	0	0	1	0	0	1	0.08
Soft rot		*Aspergillus* sp.	17	2	2	0	0	1	7	4	33	2.75
Soft rot		*Thysanophora penicillioides*	0	1	0	0	0	0	0	0	1	0.08
	Nectriceae											
Soft rot		*Cylindrocarpon oidium*	0	0	0	0	0	1	1	0	2	0.17
Soft rot		*Cylindrocarpon* sp.	3	1	0	1	0	5	12	0	22	1.83
Soft rot		*Cylindrocladium scoparium*	0	0	0	0	0	0	2	0	2	0.17
Soft rot		*Fusarium ventricosum*	5	2	0	0	2	26	19	0	54	4.5
Soft rot		*Fusarium moniliforme*	2	0	0	0	0	2	0	2	6	0.5
Soft rot		*Nectria* sp.	0	0	0	0	0	0	3	0	3	0.25
	Pleosporaceae											
Soft rot		*Bipolaris oryzae*	0	0	2	0	0	0	0	8	10	0.83
	Saccharomycetaceae											
Non rot		*Candida* sp.	0	0	0	0	0	1	9	0	10	0.83
	Scopulariopsis											

Appendix 1. Cont'd

Phylum Type of rot fungi	Classification	Genera/Species	Dry Dip	Dry Cleis	Dry BB	Dry DD	Dry DC	Wet Dip	Wet Cleis	Wet BB	Total Iso	% Iso
Soft rot		*Scopulariopsis asperula*	0	0	0	0	0	0	3	0	3	0.25
	Unclassified order											
Soft rot		*Mammaria* sp.	0	4	0	0	0	0	0	0	4	0.33
Non rot		*Phaeotrichospaeria* sp.	0	0	0	0	0	0	1	0	1	0.08
	Xylariaceae									0	0	
Soft rot		*Demotophora* sp.	0	1	0	0	0	0	0	1	2	0.17
Basidiomycota												
	Agaricaceae											
White rot		*Coprinus* sp.	0	0	0	0	0	1	0	0	1	0.08
	Mitosporic Agaricomycotina											
White rot		*Sporotrichum* sp.	3	7	0	0	0	40	9	0	59	4.92
Oomycota												
	Pythiaceae											
Soft rot		*Pythium* sp.	0	0	0	0	0	24	1	0	25	2.09
Zygomycota												
	Cunninghamellaceae											
Soft rot		*Cunninghamella* sp.	0	0	0	0	0	10	0	0	10	0.83
	Mucoraceae										0	
Soft rot		*bsidia clindrospora*	0	1	0	0	0	0	0	0	1	0.08
Soft rot		*Absidia* sp.	0	1	0	0	0	1	4	0	6	0.5
Soft rot		*Gongronella* sp.	2	1	0	0	0	0	6	0	9	0.75
Soft rot		*Mucor* sp.	0	2	0	2	0	2	3	0	9	0.75
	Mortierella											
Soft rot		*Mortierella* sp.	0	0	3	0	0	1	6	0	10	0.83
Total isolates	136	195	21	22	37	429	318	41	1199	100		
Total species	23	27	9	11	10	33	40	12				
Exclusive		No. species	4	5	0	1	1	6	13	3		
Common		Dip + Cleis		10					18			
		Dip + BB		0					2			
		Cleis + BB		1					1			
		Dip + Cleis + BB		6					4			

Dip=*Dipterocarpus*, Cleis=*Cleistocalyx*, BB=*Balakata*, DD=dead *Dipterocarpus*, DC=dead *Cleisocalyx*, Total Iso=total isolate, % iso=% isolate.

Appendix 1.
b) Identification and numbers of fungal isolates from inside and outside the cavities of Diptercarpus and Cleistocalyx.

Phylum/Species	Dry				Wet			
	Dipterocrpus		*Cleistoclayx*		*Dipterocarpus*		*Cleistoclayx*	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Ascomycota								
Bionectriaceae								
Gliocladium roseum	1							
Candelariaceae								
Candelariella sp.	1				1			
Capnodiales								
Fumago sp.								3
Chaetomiaceae								
Achaetomium sp.							2	
Chaetomium sp.							1	
Chaetosphaeriaceae								
Carpoligna sp.								
Codinaea sp.								2
Dipodascaceae								
Dipodascus sp.			2					
Galactomyces geotrichum							1	
Hypocreaceae								
Acremonium sp.	3		8			2	2	1
Cylindrocladium sp.		2	3		4		5	1
Fusarium ciliatum			1					
Fusarium roseum	1							
Fusarium solani	5		4		9	5	4	3
Fusarium sp.	10	1	49		18	7	18	12
Gliocladium virens	2		9		36	5	40	5
Gliocladium viride					2			
Gliocladium sp.	22	2	24	1	89	11	21	1
Trichoderma hamatum					2		2	
Trichoderma harzianum	1				1	1		
Trichoderma koningi					1		1	
Trichoderma spirale								
Trichoderma sp.	24	2	50	3	65	31	65	19
Verticillium sp.	3		4		8	1	5	
Microascaceae							3	
Microascus sp.								
Mitosporic Ascomycota								
Gliomastix sp.			1			1		
Humicola sp.	4		1		1	1		
Papulaspora sp.					1		1	
Phoma sp.								2
Trichocladium sp.	3							

Appendix 1. Cont'd

Phylum/Species	Dry				Wet			
	Dipterocrpus		*Cleistoclayx*		*Dipterocarpus*		*Cleistoclayx*	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Ascomycota								
Mitosporic Calosphaeriaceae								
Phialophora richardsiae			3				1	
Mitosporic Dermateaceae								
Trichosporiella sp.			4					
Mitosporic Eremomycetaceae								
Arthrographis cuboidea								
Mitosporic Leptoshaeriaceae								
Coniothyrium sp.					4			
Epicoccum sp.							1	
Mitosporic Magnaporthaceae								
Phialophora sp.					2			
Mitosporic Microascaceae								
Graphium putredinis					2		5	
Graphium sp.							1	1
Mitosporic Pezizaceae								
Oedocephalum sp.							1	
Mitosporic Pezizomycotina								
Torula herbarum								1
Torula sp.	3							
Mitosporic Trichocomaceae								
Aspergillus parasiticus						1		
Aspergillus sp.	15	2	2			1	7	
Paecilomyces victoriae								
Paecilomyces sp.	4		1		2			
Penicillium sp.	7	3	4				1	
Thysanophora penicillioides			1					
Nectriceae								
Cylindrocarpon oidium					1		1	
Cylindrocarpon sp.	3		1		5		10	2
Cylindrocladium scoparium							2	
Fusarium moniliforme	2				2			
Fusarium ventricosum	5		2		17	9	8	11
Nectria sp.							3	
Pleosporaceae								
Bipolaris oryzae								
Saccharomycetaceae								
Candida sp.					1		9	
Scopulariopsis								
Scopulariopsis asperula							3	

Appendix 1. Cont'd

Phylum/Species	Dry				Wet			
	Dipterocrpus		*Cleistoclayx*		*Dipterocarpus*		*Cleistoclayx*	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Unclassified order								
Mammaria sp.			3	1				
Phaeotrichospaeria sp.							1	
Xylariaceae								
Demotophora sp.			1					
Basidiomycota								
Agaricaceae								
Coprinus sp.						1		
Mitosporic Agaricomycotina								
Sporotrichum sp.	3		7		26	14	9	
Oomycetes								
Pythiaceae								
Pythium sp.					24		1	
Zygomycota								
Cunninghamellaceae								
Cunninghamella sp.					10			
Mortierellaceae								
Mortierella sp.					1		6	
Mucoraceae								
Abisidia clindrospora			1					
Abisidia sp.			1		1		4	
Gongronella sp.		2	1				6	
Mucor sp.			2		2		2	1
Total isolates	122	14	190	5	338	91	255	63
Total species	21	7	26	3	29	15	37	14

Appendix 2. Properties of wood sampled from *Dipterocarpus gracilis*, *Cleistocalyx nervosum* and *Balakata baccata* (referred to as *D. costata, Syzygium cumini, Sapium baccatum,* irrespectively in Thonanont et. al, 1985).

Tree species	**Moisture content %**	**Toughness kg-m**	**Strength Kg/cm²**	**Hardness kg**
Moderate hardwood with high strength				
D. gracilis	12	4.03	661	772
Moderate hardwood				
C. nervosum	12	2.86	473	809
Softwood				
B. baccata	187	1.90	167	176