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Thailand's amazing diversity: up to 96% of fungi in northern Thailand may be novel

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Abstract

Fungi have been often neglected, despite the fact that they provided penicillin, lovastatin and many other important medicines. They are an understudied, but essential, fascinating and biotechnologically useful group of organisms. The study of fungi in northern Thailand has been carried out by us since 2005. These studies have been diverse, ranging from ecological aspects, phylogenetics with the incorporation of molecular dating, taxonomy (including morphology and chemotaxonomy) among a myriad of microfungi, to growing novel mushrooms, and DNA-based identification of plant pathogens. In this paper, advances in understanding the biodiversity of fungi in the region are discussed and compared with those further afield. Many new species have been inventoried for the region, but many unknown species remain to be described and/or catalogued. For example, in the edible genus *Agaricus*, over 35 new species have been introduced from northern Thailand, and numerous other taxa await description. In this relatively well known genus, 93% of species novelty is apparent. In the microfungi, which are relatively poorly studied, the percentage of novel species is, surprisingly, generally not as high (55–96%). As well as Thai fungi, fungi on several hosts from Europe have been also investigated. Even with the well studied European microfungi an astounding percentage of new taxa (32–76%) have been discovered. The work is just a beginning and it will be a daunting task to document this astonishingly high apparent novelty among fungi.

Keywords *Agaricus* · *Amanita* · *Colletotrichum* · *Cornus* · Fungal diversity · Pandanaceae · Rosaceae · *Rosa* · Teak fungi

Introduction

Fungi are an incredibly understudied, but an essential, fascinating and biotechnologically useful group of organisms. The fungi of northern Thailand have been studied by Hyde and coworkers since 2005. The studies have been diverse, ranging across ecology, traditional taxonomy, phylogenetics, evolution, microbial community and chemotaxonomy (Thongkantha et al. 2008; Pinnoi et al. 2010; Phookamsak et al. 2015; Wurzbacher et al. 2017; Norphanphoun et al. 2018; Tedersoo et al. 2018), to growing novel mushrooms (Thongklang et al. 2014), molecular identification of endophytes and plant pathogens (Jayawardena et al. 2016b; Doilom et al. 2017b), and identification of entomophagous fungi (Xiao et al. 2017, 2018).

Although there are many negative facets to fungi (see Hyde et al. 2018), they are an essential component of most ecosystems and without them there would be ecological imbalance, and possibly mankind would not survive on earth (Watkinson et al. 2015). They are major contributors to nutrient cycling, and the main organisms which can degrade lignocellulose in wood and leaves (Pointing et al. 2005; Bucher et al. 2004; Tang et al. 2005); without them we would live amongst mountains of dead trees (Gadd et al. 2007). Many species exist as symbionts with plants

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and promote plant growth, including crops in many environments (Abiala et al. 2013). Fungi occur in the guts of herbivores and help to digest the consumed grasses, while some species are also passed out with the faeces and degrade dung (Kruys et al. 2015; Paul et al. 2018). Some species infect and kill insects (Sung et al. 2007), others cause disease of humans, their hair and skin (Gostinčar et al. 2018; Hyde et al. 2018) and many fungi are extremely important plant pathogens causing major yield losses, and are thus of considerable agricultural and quarantine importance (Cai et al. 2011; Hyde et al. 2014). Fungi also have an incredible biotechnological potential (Pointing and Hyde 2001; Hyde et al. 2010).

The fungi of northern Thailand have been studied by Hyde and coworkers for more than a decade and we have documented the biodiversity of both macro- and micro-fungi and more than 500 species have been introduced. Mushroom groups have revealed an amazingly high amount of novelty, the same result being apparent for the microfungal plant pathogens, saprobes, endophytes and epitypes. Other parts of Thailand have been less-well studied for fungi, however studies of BIOTEC, Hyde and coauthors, and others, have revealed an amazing noveltly (e.g. Pinnoi et al. 2006; Pinruan et al. 2007; Tibpromma et al. 2018).

In this paper, the advances made in understanding the diversity of fungi in northern Thailand are presented together with details for eight examples presented from relatively conspicuous or important groups. This data shows that the species novelty in northern Thailand is amazingly between 55–96%. The data are being extended two host groups in Europe, which also show a surpising unexpected amount of novelty.

Results and discussion

Studies of fungi in the conspicuous macroscopic genera *Agaricus*, *Amanita*, and *Lactarius*, the well studied microscopic pathogenic genera *Colletotrichum* and *Diaporthe*, the less well-studied hosts Pandanaceae and *Tectona grandis*, and foliar epiphytes in northern Thailand have revealed a novelty of between 55–96% (Table 1). Although we provide examples from these few selected groups, we feel they are both important and are well-studied elsewhere and thus may be representative of the majority of fungal groups. This astonishing novelty in such conspicuous and well studied genera and groups points to the overall fact that fungi are poorly studied and if one chooses an understudied genus such as *Phaeosphaeria* or poorly studied hosts such as ferns, one would expect to find an even higher percentage of novelty.

Novelty in conspicuous mushrooms

From our experience, it is easier and more common to collect larger and visible species; thus mushrooms (e.g. *Agaricus*, *Russula*) and larger ascomycetes (e.g. *Xylaria*, *Hypoxylon*) have generally been better studied (Daranagama et al. 2018). Because of this, we would expect to find a lower novelty in the commonly collected mushroom genera. However, we provide examples of the novelty of species found in three conspicuous genera, mostly in northern Thailand. We show that between 83–93% of these species are novel.

Agaricus

Species of *Agaricus* (Agaricales, Basidiomycota) are saprobes which grow in various habitats, such as grassland, forests, leaf litter, sand dunes and even occur in some arid areas (Parra 2008; Karunarathna et al. 2016). During the last decade, the number of known *Agaricus* species has increased rapidly especially in tropical regions where, thanks to the advances in molecular phylogenetics, many new species have been revealed. From January 2000 to September 2018, almost 200 new species have been described and more than 500 *Agaricus* species are now recognized (Chen et al. 2017; Karunarathna et al. 2016; Kerrigan 2016; Parra et al. 2018). Of these new species, 55% (102) were described from Asia, and most of these from China and northern Thailand (Ariyawansa et al. 2015; Bashir et al. 2018: Chen et al. 2012, 2015, 2016, 2017; Dai et al. 2016; Gui et al. 2015; He et al. 2017, 2018a, b; He and Zhao 2015; Hyde et al. 2017; Kaur et al. 2016; Karunarathna et al. 2014; Li et al. 2014, 2016; Liu et al. 2015; Mahdizadeh et al. 2018; Thongklang et al. 2014, 2016; Wang et al. 2015; Zhang et al. 2017b; Zhao et al. 2012a, b, 2016; Zhou et al. 2016).

We have collected more than 500 *Agaricus* specimens since 2005, mainly in northern Thailand. To date 38 new species have been formally introduced (Tables 1, 2) with perhaps another 30 species awaiting description. In addition, the cosmopolitan species *A. subrufescens*, *A. endoxanthus* ("great traveller") and *A. microvolvatulus* are confirmed new records for Thailand (Thongklang et al. 2014; Wisitrassameewong et al. 2012a; Zhao et al. 2012a), while two species bearing identical ITS sequences to the types of *A. heterocystis* and *A. xanthosarcus* need further morphological study to confirm their identity (Zhao et al. 2011). Thus, more than 93% of the *Agaricus* species collected in Thailand are new to science.

This is remarkable novelty for a mushroom genus that is highly prized for its edible species. If only a few of the new *Agaricus* species could be cultivated, and were edible and

Table 1 Fungal numbers reported from Thailand discussed in this study

Subject	Number of species reported before our study	Number of these species confirmed by molecular data	Number of species collected	Number of described new species	Number remaining undescribed	New records of known species to Thailand	Percentage novelty (%)	Expected new species in future studies
Agaricus	17	0	75	38	32	5	93	40+
Amanita	27	3	69	17[a]	40	9	83	25+
Lactarius subg. *Russularia*	0	0	23	17[b]	3	3	87	30+
Colletotrichum	12	5	39	16	10	8	67	50+
Diaporthe	26	0	26	13	12	1	96	100+
Pandanaceae	87	3	93	54	15	21	74	100+
Tectona grandis	15	0	53	24	5	24[c]	55	100
Foliar epiphytes	6	0	74	42	23	9	88	100

[a]Three species recorded by Li et al. (2016); [b]One species recorded by Verbeken et al. (2014); [c]Two species recorded by Meeboon and Takamatsu (2017)

tasty, then numerous new species could be introduced to international cuisine (Thawthong et al. 2014). *Agaricus subrufescens* is an important medicinal species (Wisitrassameewong et al. 2012a), and we predict that many of the other species could also be cultivated and used as functional foods and medicine. It must be noted that before 2011, only 17 species of *Agaricus* were recorded in Thailand and these were published in local reports and books (Zhao 2008; Chandrasrikul et al. 2011). However, of these 17 identifications, many were linked to species originally described from Europe, such as *A. campestris*, *A. bisporus* and *A. bitorquis*; these determinations are doubtful and cannot be confirmed due to a lack of herbarium material, detailed descriptions and molecular data.

Amanita

Amanita is an important genus of mushrooms and its section *Phalloideae* includes several species that are widely recognized as the most poisonous mushrooms in the world (Hyde et al. 2018). The genus also includes hallucinogenic species such as *A. muscaria* (type species of *Amanita*) and *A. pantherina*, as well as prized edible mushrooms, such as *A. caesarea* and other species of sect. *Caesarea*. Most species of *Amanita* are considered to be ectomycorrhizal and their distribution in forests and heaths including Betulaceae, Dipterocarpaceae, Fabaceae, Myrtaceae, Pinaceae, and Salicaceae, suggests that they play a critical role in forest ecosystems worldwide (Weiß et al. 1998; Yang 1997; Zhang et al. 2004). There are 36 taxa reported as non-ectomycorrhizal (Wolfe et al. 2012). As of July 2018, *Amanita* comprises just under 1000 taxa of which 600 have validly published names, 305 are known by provisional names or temporary codes, and the remainder have misapplied, invalid or illegitimate names (Tulloss and Yang 2018; Cui et al. 2018). Cui et al. (2018) dealt with the rearrangement of the *Amanita*, mainly based on Chinese materials. They recognised 156 taxa of *Amanita* in China and reported on several others, but it is anticipated that additional species remain to be formally named. Although they gave no update on the total number of species in *Amanita*. Cui et al. (2018) revisited its classification and recognised eleven sections and three subgenera (*Amanita*, *Amanitina* and *Lepidella*).

Prior to the current study, 25 species (with one species affinis) of *Amanita* had been reported from northern Thailand (Sanmee et al. 2008). Since 2012, we have collected more than 250 specimens of *Amanita*, mainly in the north (Table 3). Of all *Amanita* species collected in Thailand, three are confirmed records of previously recorded taxa, nine are new records of known species, 17 are new species (three from Li et al. 2016) and 40 are species awaiting description. Thus, 83% of the collected species of Thai *Amanita* are new to science.

Lactarius subg. *Russularia*

Lactarius species are commonly known as milk-caps due to their latex exudation when the basidiomata are injured. They form ectomycorrhizal associations with diverse groups of terrestrial plants, both deciduous and coniferous. Some *Lactarius* species, such as *L. deliciosus* (L. Fr.) Gray, *L. indigo* (Schwein.) Fr. and *L. hatsudake* Tanaka are sought after mushrooms due to their pleasant taste. Of the

Table 2 *Agaricus* species recorded from Thailand (novel species are in bold)

Taxon	References
Agaricus albosquamosus	Zhao et al. (2016)
Agaricus angusticystidiatus	He et al. (2018a)
Agaricus atrodiscus	Ariyawansa et al. (2015)
Agaricus badioniveus	Chen et al. (2017)
Agaricus bisporiticus	Thongklang et al. (2014)
Agaricus brunneolutosus	Chen et al. (2017)
Agaricus brunneosquamulosus	Chen et al. (2015)
Agaricus chiangmaiensis	Karunarathna et al. (2014)
Agaricus endoxanthus	Zhao et al. (2012a)
Agaricus erectosquamosus	Zhao et al. (2016)
Agaricus exilissimus	Ariyawansa et al. (2015)
Agaricus fimbrimarginatus	Chen et al. (2017)
Agaricus flammicolor	Chen et al. (2017)
Agaricus flavicentrus	Liu et al. (2015)
Agaricus flocculosipes	Zhao et al. (2012b)
Agaricus fuscopunctatus	Thongklang et al. (2014)
Agaricus haematinus	Ariyawansa et al. (2015)
Agaricus hanthanaensis	Liu et al. (2015)
Agaricus heterocystis	Zhao et al. (2011)
Agaricus inthanonensis	Zhao et al. (2016)
Agaricus leucocarpus	Chen et al. (2017)
Agaricus leucolepidotus	Zhao et al. (2016)
Agaricus luteofibrillosus	Li et al. (2016)
Agaricus luteopallidus	Chen et al. (2017)
Agaricus megacystidiatus	Karunarathna et al. (2014)
Agaricus megalosporus	Chen et al. (2012)
Agaricus microvolvatulus	Thongklang et al. (2014)
Agaricus murinocephalus	Zhao et al. (2012a)
Agaricus niveogranulatus	Chen et al. (2015)
Agaricus parvibicolor	Liu et al. (2015)
Agaricus patris	Chen et al. (2017)
Agaricus pseudolangei	Ariyawansa et al. (2015)
Agaricus purpureofibrillosus	Chen et al. (2017)
Agaricus robustulus	Chen et al. (2017)
Agaricus sodalis	Liu et al. (2015)
Agaricus sordidocarpus	Chen et al. (2015)
Agaricus subrufescens	Wisitrassameewong et al. (2012b)
Agaricus subtilipes	Zhao et al. (2016)
Agaricus suthepensis	Zhao et al. (2016)
Agaricus toluenolens	Chen et al. (2015)
Agaricus variicystis	Zhao et al. (2016)
Agaricus xanthosarcus	Zhao et al. (2011)
Agaricus brunneogracilis	Zhou et al. (2016)

three currently accepted subgenera, *Lactarius* subg. *Russularia* (Fr.) Kauffman is a difficult group to study due to the similarity in macromorphological and latex features amongst species. Species in this subgenus can be recognised in the field by the orange to warm brown to reddish brown fruiting bodies, which are typically dry and fragile, the unchanging latex and the smell of Pentatomidae bugs. In Thailand, although subg. *Russularia* species are abundant in nature, they have been often overlooked by locals because they are small and fragile and have a poor taste. Subg. *Russularia* is one of the dominant mushroom groups in terms of the species numbers and numbers of basidiomata distributed in Thai forests. They are associated with several dominant genera of trees, e.g. *Dipterocarpus*, *Shorea*, *Castanopsis*, *Lithocarpus*, *Quercus*, *Betula* and *Pinus*. Until recently, knowledge of *Lactarius* subg. *Russularia* in Thailand was very poor; only *L. chichuensis* W.F. Chiu, *L. gracilis* Hongo, and *L. subzonarius* Hongo were reported (Le 2007). In addition, European names such

Table 3 *Amanita* species recorded from Thailand (novel species are in bold)

Taxon	References
Amanita atrobrunnea	Li et al. (2016)
Amanita ballerina	Thongbai et al. (2017a)
Amanita brunneitoxicaria	Thongbai et al. (2017a)
Amanita brunneoprocera	Thongbai et al. (2018)
Amanita brunneosquamata	Thongbai et al. (2018)
Amanita brunneoumbonata	Thongbai et al. (2018)
Amanita castanea	Thongbai et al. (2016)
Amanita cinnamomea	Thongbai et al. (2018)
Amanita concentrica	Thongbai et al. (2016)
Amanita digitosa	Li et al. (2016)
Amanita esculenta	Thongbai et al. (2018)
Amanita flavidocerea	Thongbai et al. (2018)
Amanita flavidogrisea	Thongbai et al. (2018)
Amanita fuligineoides	Thongbai et al. (2017a)
Amanita gleocystidiosa	Li et al. (2016)
Amanita hemibapha sensu lato	Sanmee et al. (2008)
Amanita luteoparva	Thongbai et al. (2018)
Amanita macrocarpa	Thongbai et al. (2017a)
Amanita cf. *oberwinklerana*	Thongbai et al. (2017a)
Amanita pyriformis	Li et al. (2016)
Amanita pseudoporphyria	Sanmee et al. (2008)
Amanita rimosa	Thongbai et al. (2016)
Amanita rubromarginata	Thongbai et al. (2016)
Amanita rubrovolvata	Sanmee et al. (2008)
Amanita cf. *spissacea*	Thongbai et al. (2017a)
Amanita strobilipes	Li et al. (2016)
Amanita suborientifulva	Thongbai et al. (2018)
Amanita subovalispora	Thongbai et al. (2018)
Amanita zangii	Thongbai et al. (2016)

as *L. camphoratus* (Bull.: Fr.) Fr., were often applied for Thai species. Thus, the biodiversity of *Lactarius* subg. *Russularia* in northern Thailand was explored (Wisitrassameewong et al. 2014a, b, 2015; Liu et al. 2015).

More than 100 collections of subg. *Russularia* were made since 2007, most from the four northern provinces (Chiang Mai, Chiang Rai, Mae Hong Son and Lampang). For species delimitation, we relied on morphology, molecular phylogeny based on ITS and *rpb2* regions and to a lesser extent the ecology of host genera. Seventeen novel species (Table 4) were published, along with three new records for Thailand, and another three are new species awaiting description. Thus, in *Lactarius* subg. *Russularia* 87% of species collected in northern Thailand are new to science. We predict that with more extensive sampling, more than 30 new cryptic species will be found in coming years.

Together with collaboration from Mycology laboratory of Ghent University, we compared our data with data of European species in order to investigate the eventual intercontinental conspecificity of the mycota found in European temperate and Asian tropical regions. There is no case of conspecificity between European and Thai species. Therefore, European or North American names should generally not be used for Thai taxa. Apart from our described species, the sequestrate *L. falcatus* Verbeken & Van de Putte was also reported from deciduous forest in northern Thailand by Verbeken et al. (2014).

Table 4 *Lactarius* subg. *Russularia* species recorded from Thailand (novel species are in bold)

Taxa	References
Lactarius aquosus	Wisitrassameewong et al. (2015)
Lactarius atrobrunneus	Liu et al. (2015)
Lactarius austrorostratus	Wisitrassameewong et al. (2015)
Lactarius chichuensis	Wisitrassameewong et al. (2015)
Lactarius crenulatulus	Wisitrassameewong et al. (2014a)
Lactarius falcatus	Verbeken et al. (2014)
Lactarius fuscomaculatus	Wisitrassameewong et al. (2015)
Lactarius grabrigracilis	Wisitrassameewong et al. (2014b)
Lactarius gracilis	Wisitrassameewong et al. (2014b)
Lactarius inconspicuus	Wisitrassameewong et al. (2015)
Lactarius kesiyae	Wisitrassameewong et al. (2015)
Lactarius laccarioides	Wisitrassameewong et al. (2014a)
Lactarius pasohensis	Wisitrassameewong et al. (2014a)
Lactarius perparvus	Wisitrassameewong et al. (2014b)
Lactarius politus	Liu et al. (2015)
Lactarius rubrobrunneus	Wisitrassameewong et al. (2015)
Lactarius rubrocorrugatus	Wisitrassameewong et al. (2015)
Lactarius sublaccarioides	Wisitrassameewong et al. (2014a)
Lactarius subzonarius	Hongo (1957)
Lactarius tangerinus	Wisitrassameewong et al. (2015)

Novelty in plant pathogens

Diseases caused by plant pathogens may result in considerable losses to food production, as exemplified by black stem rust of wheat (*Puccinia* spp., Zadoks 1985), late blight of potato (*Phytopthora infestans*, Fry et al. 2013) and rice blast disease (*Magnaporthe oryzae*, Ou 1980). The introduction of exotic plant pathogens may also seriously affect farming, forestry and the environment (Jayawardena et al. 2016a; Hyde et al. 2018), as well as global plant trade resulting in huge economic losses to a country (Jayawardena et al. 2016a). Plant pathogens continue to develop resistance against chemicals and host crop defence mechanisms (Crouch 2014) and this has become a challenge in developing control strategies. Most pathogens are microfungi and although the fungus may not be easily seen, the disease symptoms they cause are both highly visual and often occur in epidemic proportions resulting in large yield losses. For this reason, plant pathogens are very well studied and not a group where we would expect to find a high diversity of novel species. In this study, we show that in two prominent plant pathogenic genera collected in northern Thailand, 67% of species in *Colletotrichum* and 96% in *Diaporthe* are novel.

Colletotrichum

Colletotrichum is one of the most important phytopathogenic genera worldwide affecting quality and yield of many economical crops (Hyde et al. 2009; Cannon et al. 2012; Jayawardena et al. 2016b). In a checklist of plant diseases in Thailand (Giatgong 1980), 12 named species of *Colletotrichum* were listed, while undetermined species were recorded from many different hosts. This host-fungi index was based solely on past literature and taxa were named based on morphological characters.

Molecular data are essential to identify *Colletotrichum* to species level (Shenoy et al. 2007; Cai et al. 2009; Cannon et al. 2012; Hyde et al. 2009, 2014; Jayawardena et al. 2016b; Damm et al. 2019) and therefore these old records must be treated as dubious. For example, in earlier studies carried out in Thailand many species were identified as *C. acutatum* and *C. gloeosporioides*. Both of these are now considered as species complexes (Jayawardena et al. 2016b). As there is no herbarium material or cultures we cannot recheck these records. We have been studying *Colletotrichum* in Thailand since 2007. *Colletotrichum gloeosporioides*, which was thought to be a common pathogen in tropics, turned out not to be that common and may even not be present (Phoulivong et al. 2010). Phoulivong et al. (2010) analyzed DNA sequence data of 25 isolates from eight tropical fruits, which were morphologically identified as *C. gloeosporioides* in previous studies. Contrary to previous understanding, none of the 25 isolates clustered with the epitype of *C. gloeosporioides* in the multi-gene phylogenetic analyses. Than et al. (2008a) identified *C. acutatum*, *C. capsici* and *C. gloeosporioides* as the causal agents of anthracnose in chili in Thailand based on morphological characters. However, with the use of ITS and β-tubulin sequence data, Than et al. (2008b) showed that *C. acutatum*, *C. capsici*, *C. gloeosporioides* and *C. siamenese* are the causal agents of chili anthracnose in Thailand. Morphological characters can be used to differentiate *Colletotrichum* into species complexes (Hyde et al. 2014; Jayawardena et al. 2016b) but, they cannot be used to separate species within a complex (Phoulivong et al. 2010; Jayawardena et al. 2016b).

We have collected more than 200 specimens of *Colletotrichum* mainly in north Thailand. Of these, eight are new records (hosts/locations), 16 are new species (Table 5) and ten new species that await description. Thus, in *Colletotrichum* 67% of collected species are new to science (Table 1). The remaining collection representing about 40 species need either more material or additional sequences other than ITS rDNA for a formal description. We predict that with extensive sampling, more cryptic species will be introduced in coming years, with perhaps more than 50 new species.

Diaporthe

Diaporthe (syn. *Phomopsis*) species are well known as pathogens, endophytes or saprobes on a range of economical crops, ornamentals and forest trees (Rehner and Uecker 1994; Santos and Phillips 2009; Santos et al. 2011; Udayanga et al. 2011, 2012a, b, 2014; Hyde et al. 2014; Dissanayake et al. 2015, 2017b, c). In the past species of *Diaporthe* were introduced largely on the basis of host association, which resulted in a proliferation of species names. However, it is now recognised that many of the species are not host-specific and a single species can be found on more than one host (Dissanayake et al. 2017b).

Only a few studies related to *Diaporthe*/*Phomopsis* pathogens have been conducted in Thailand. Hyde (1991) introduced a novel *Phomopsis* species: *Phomopsis mangrovei*, from intertidal prop roots of *Rhizophora apiculata* in Thailand. Sontirat et al. (1994) listed eight unnamed *Diaporthe* species and four unnamed *Phomopsis* species on various host plants in the checklist of Thai pathogens. Based on molecular data, Udayanga et al. (2012a) reported eleven undescribed *Diaporthe* isolates. Oeurn et al. (2015) found another *Phomopsis* sp. on dragon fruit stems in Loei Province, Thailand, but no molecular data were used to support its identity. A survey of leaf spots associated with disease of durian caused by *Phomopsis durionis* was conducted by Tongsri et al. (2016). Thus, until the incorporation of molecular data, 26 *Diaporthe*/*Phomopsis* taxa had been reported to cause diseases on various hosts in Thailand.

We have been studying *Diaporthe* in Thailand since 2012. Twenty-six species were collected mainly in the north, of which none are confirmed existing records, include 14 species formally described (Table 1). Of all *Diaporthe* species collected in Thailand, 13 are new species and one is new species record that we have described (Table 6) and another twelve are new species waiting to be described. thus, 96% of collected *Diaporthe* species in northern Thailand are new to science.

Novelty in fungi on various hosts

Another approach to studying fungal diversity is to target a certain host, and make an inventory of the fungi that are associated with it, either as pathogens, mycorrhizal symbionts, endophytes or epiphytes. Tropical hosts are generally not well studied and fungal novelty might thus be high. We discuss fungi on Pandanaceae and teak (*Tectona grandis*), and show that 55–74% of species are novel.

Pandanaceae

The plant family Pandanaceae belongs to monocotyledonous and its species have a worldwide distribution and occur throughout Thailand. Microfungi on Pandanaceae in Thailand have been relatively well studied, although the taxonomic studies lacked molecular data (Manoch et al. 1986; Sivanesan 1987; Tokumasu et al. 1990; Thienhirun 1997; Sivichai et al. 1998; Goh et al. 1999; Pinnoi et al. 2004; Thongkantha et al. 2008; Whitton et al. 2012).

The fungi on Pandanaceae in Thailand have been studied by us since 2014. More than 150 specimens were collected, comprising 99 species. Of all the species we collected on Pandanaceae in Thailand, three are confirmed existing records, 21 are new records, 54 are new species (Tables 1, 7) and another 15 are new species waiting to be described. Thus, on Pandanaceae 74% of species are new to science.

Teak fungi

Teak is one of the most economically valuable hardwood trees globally. The genus *Tectona* is a member of the family Lamiaceae belonging to order *Laminales*. Teak is distributed in many countries, and Thailand has a natural distribution of teak forests. Studies on the fungi on teak in

Table 5 *Colletotrichum* species recorded from Thailand (novel species from Thailand are in bold

Species	Host	References
Colletotrichum acidae	*Phyllanthus acidus*	Samarakoon et al. (2018)[a]
Colletotrichum acutatum	*Capsicum annuum*	Than et al. (2008b)
	Fragaria sp.	
	Fragaria sp.	Photita et al. (2004)
	Capsicum annuum	Suwannarat et al. (2017)[a]
	Capsicum annuum	Diao et al. (2017)[a]
Colletotrichum aeschynomenes	*Manihot esculenta*	Sangpueak et al. (2018)[a]
Colletotrichum asianum	*Coffea arabica*	Prihastuti et al. (2009)
	Mangifera indica	
Colletotrichum boninense	*Dendrobium* sp.	Ma et al. (2018)[a]
	Manihot esculenta	Sangpueak et al. (2018)[a]
Colletotrichum brevisporum	*Neoregelia* sp., *Pandanus pygmaeus*	Noireung et al.(2012)[a]
Colletotrichum cariniferi	*Dendrobium cariniferum*	Ma et al. (2018)[a]
Colletotrichum chiangraiense	*Dendrobium* sp.	Ma et al. (2018)[a]
Colletotrichum citricola	*Dendrobium* sp.	Ma et al. (2018)[a]
Colletotrichum cordylinicola	*Cordyline fruticosa*	Phoulivong et al. (2010)
Colletotrichum doitungense	*Dendrobium fimbriatum*	Ma et al. (2018)[a]
Colletotrichum endophytica	*Pennisetum purpureum*	Manamgoda et al. (2013)[a]
Colletotrichum fructicola	*Coffea arabica*	Phoulivong et al. (2010)[a]
	Capsicum annuum	Than et al. (2008a, b), Diao et al. (2017)[a]
	Carica papaya	
	Dimocarpus longan	
	Cymbopogon citratus,	Manamgoda et al. (2013)[a]
	Pennisetum purpureum	
	Dendrobium sp.	Ma et al. (2018)[a]
Colletotrichum fusiforme	Unknown	Ariyawansa et al. (2015)[a]
Colletotrichum gigasporum	*Alocasia* sp.,	Liu et al. (2014)[a]
	Hibiscus rosa-sinensis	
Colletotrichum gloeosporioides	*Capsicum annuum, Fragaria* sp., *Mangifera indica*	Than et al. (2008a, b)
	Magnolia liliifera	Promputtha et al. (2004)
	Stylosanthes fruticosa, Stylosanthes hamata, Stylosanthes humilis, Stylosanthes scabra	Masel et al.(1993)[N/A]
	Alpinia malaccensis, Draceana sanderiana, Eupatorium thymifolia, Alpinia galanga, Mangifera indica, Musa acuminata, Manihot esculenta	Photita et al. (2004), Sangpueak et al. (2018)[a]
Colletotrichum graminicola	*Rottboellia cochinchinensis*	Sherriff et al. (1995)[N/A]
	Manihot esculenta	Sangpueak et al. (2018)[a]
Colletotrichum musae	*Musa acuminata, Musa* sp.	Su et al. (2011)[a]
Colletotrichum orchidearum	*Hymenocallis* sp.	Damm et al. (2019)[a]
Colletotrichum orchidophilum	*Dendrobium* sp.	Ma et al. (2018)[a]
Colletotrichum pandanicola	*Pandanus* sp.	Tibpromma et al. (2018a)[a]
Colletotrichum parallelophorum	*Dendrobium* sp.	Ma et al. (2018)[a]
Colletotrichum scovillei	*Capsicum annuum, Capsicum* sp.	Damm et al. (2012)[a]
Colletotrichum siamense	*Coffea arabica*	Phoulivong et al. (2010)
	Capsicum annuum, Hymenocallis sp.	Than et al. (2008a, b), Yang et al. (2009)[a]
	Cymbopogon citratus, Pennisetum purpureum	Manamgoda et al. (2013)[a]
Colletotrichum syzygiicola	*Citrus aurantifolia, Syzygium samarangense*	Udayanga et al. (2013)[a]
Colletotrichum tropicale	*Pennisetum purpureum*	Manamgoda et al. (2013)[a]

Table 5 (continued)

Species	Host	References
Colletotrichum tropicicola	*Citrus maxima, Paphiopedilum bellatulum*	Noireung et al. (2012)[a]
Colletotrichum truncatum	*Capsicum annuum, C. frutescens, Capsicum* sp., *Manihot esculenta, Solanum melongena, Vigna sesquipedalis, Glycine max, Stylosanthes hamata, Hymenocallis* sp., *Gossypium* sp.	Photita et al. (2004), Than et al. (2008a, b), Yang et al. (2009)[a], Diao et al. (2017)[a], Suwannarat et al. (2017)[a], Sangpueak et al. (2018)[a]
Colletotrichum watphraense	*Dendrobium* sp.	Ma et al. (2018)[a]

[a]Phylogenetic studies including other gene regions apart from ITS sequence data

Table 6 *Diaporthe* species recorded from Thailand (novel species from Thailand are in bold) confirmed with molecular data

Taxon	Host	References
Diaporthe aseana	Unknown dead leaf	Hyde et al. (2016)
Diaporthe collariana	*Magnolia champaca*	Perera et al. (2018)
Diaporthe garethjonesii	Unknown dead leaf	Hyde et al. (2016)
Diaporthe neoraonikayaporum	*Tectona grandis*	Doilom et al. (2016, 2017a)
Diaporthe phaseolorum	*Hylocereus undatus*	Udayanga et al. (2012a)
Diaporthe pterocarpi	*Pterocarpus indicus*	Udayanga et al. (2012b)
Diaporthe pterocarpicola	*Pterocarpus indicus*	Udayanga et al. (2012b)
Diaporthe siamensis	*Dasymaschalon* sp.	Udayanga et al. (2012b)
Diaporthe tectonae	*Tectona grandis*	Doilom et al. (2016, 2017a)
Diaporthe tectonendophytica	*Tectona grandis*	Doilom et al. (2016, 2017a)
Diaporthe tectonigena	*Tectona grandis*	Doilom et al. (2016, 2017a)
Diaporthe thunbergii	*Thunbergia laurifolia*	Udayanga et al. (2012b)
Diaporthe thunbergiicola	*Thunbergia laurifolia*	Liu et al. (2015)
Diaporthe rosae	*Rosa* sp.	Wanasinghe et al. (2018)

Expected number of new species: > 100

Thailand are few. Fifteen taxa, mostly without molecular data, have been reported from Thailand, such as *Alternaria alternata*, *Cercospora tectonae*, *Daldinia eschscholtzii*, *Hypoxylon haematostroma*, *Nigrospora sphaerica*, *Olivea tectonae* (≡ *Uredo tectonae*), *Schizophyllum commune*, *Xylaria allantoidea* and *X. feejeensis* before we commenced our research (Giatgong 1980; Lorsuwan et al. 1984; Chareprasert et al. 2006; Meeboon et al. 2007; Mekkamol 1998; Okane et al. 2008; To-anun et al. 2011).

We have studied teak fungi since 2011. More than 120 specimens were collected mainly in the north. Of all teak fungi we collected in Thailand, none were confirmed as existing records, 24 are new records (two from Meeboon and Takamatsu 2017), 24 are new species (Tables 1, 8) and five are potentially novel species awaiting description. Thus, from teak 55% of collected species are new to science.

Novelty in various habitats

Specific habitats are generally less well-studied, especially for microfungi in the tropics and therefore we might expect a high novelty if we study such a habitat in detail. In this section we look at the novelty of foliar epiphytes. These are minor plant pathogens and while some are highly visible, most are hard to observe, and as a whole have received little attention. In this study, we show that 88% of foliar epiphytes species are novel.

Foliar epiphytes

Fungal epiphytes commonly occur on plant surfaces, particularly the leaves (Carroll 1991; Gilbert and Reynolds 2002, 2005; Wu et al. 2011; Hongsanan et al. 2016b). This is a polyphyletic group belonging in the Ascomycota (Schoch et al. 2009; Li et al. 2016; Wu et al. 2011; Hyde et al. 2013; Hongsanan et al. 2016b). Fungal epiphytes, which are obligate parasites, can cause damage to host plants, e.g. resulting in lower yields, chlorosis and plant-stunting disease (Ariyawansa et al. 2015; Hongsanan et al. 2014a, 2015a, c, 2016b). The coating of hyphae on the surface of plants in some species may result in marketability problems (Chomnunti et al. 2014). The ecology and taxonomy of fungal epiphytes has been studied

Table 7 Fungal species on Pandanaceae reported in Thailand with morphological and molecular data (novel species from Thailand are in bold)

Taxa	Host	Location	References
Acremoniisimulans thailandensis	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Alternaria burnsii[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Anthostomelloides krabiensis	*Pandanus odorifer*	Krabi Province	Tibpromma et al. (2017a)
Beltrania krabiensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Beltraniella pandanicola	*Pandanus* sp.	Phuket Province	Tibpromma et al. (2018b)
Beltraniella thailandicus	*Pandanus* sp.	Chonburi Province	Tibpromma et al. (2018b)
Byssosphaeria siamensis	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Canalisporium krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Canalisporium thailandensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Cercospora capsici	*Pandanus amaryllifolius*	Chiang Mai Province	Tibpromma et al. (2018b)
Chaetomium globosum	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Cladosporium endophyticum[a]	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018a)
Clonostachys krabiensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Colletotrichum fructicola[a]	*Pandanus* sp., *Freycinetia* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Colletotrichum pandanicola	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Colletotrichum pandanicola[a]	*Pandanus* sp.	Chumphon Province	Tibpromma et al. (2018a)
Curvularia chonburiensis	*Pandanus* sp.	Chonburi Province	Tibpromma et al. (2018b)
Curvularia pandanicola	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Curvularia thailandicum	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Deniquelata barringtoniae	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Diaporthe pandanicola[a]	*Pandanus* sp.	Chumphon Province	Tibpromma et al. (2018a)
Diaporthe siamensis[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Dictyochaeta siamensis	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Dictyocheirospora pandanicola	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Dictyosporium appendiculatum	*Pandanus* sp.	Nakhon Si Thammarat Province	Tibpromma et al. (2018b)
Dictyosporium guttulatum	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Dictyosporium krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Dictyosporium pandanicola	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Distoseptispora thailandica	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Endomelanconiopsis freycinetiae[a]	*Freycinetia* sp.	Ranong Province	Tibpromma et al. (2018a)
Endopandanicola thailandica[a]	*Pandanus* sp., *Freycinetia* sp.	Chumphon Province	Tibpromma et al. (2018a)
Helicoma freycinetiae	*Freycinetia javanica*	Phang Nga Province	Tibpromma et al. (2018b)
Hermatomyces krabiensis	*Pandanus odorifer*	Krabi Province	Tibpromma et al. (2016b)
Hermatomyces krabiensis (= *H. chiangmaiensis*)	*Pandanus* sp.	Chiang Mai Province	Tibpromma et al. (2017b)
Hermatomyces pandanicola	*Pandanus odorifer*	Phang Nga Province	Tibpromma et al. (2016b)
Hermatomyces saikhuensis	*Pandanus odorifer*	Prachuap Khiri Khan Province	Tibpromma et al. (2016b)
Lasiodiplodia chonburiensis	*Pandanus* sp.	Chonburi Province	Tibpromma et al. (2018b)
Lasiodiplodia hyalina	*Pandanus* sp.	Chiang Mai Province	Tibpromma et al. (2018b)
Lasiodiplodia pandanicola	*Pandanus* sp.	Phatthalung Province	Tibpromma et al. (2018b)
Lasiodiplodia pseudotheobromae	*Pandanus* sp.	Chiang Rai Province	Tibpromma et al. (2018b)
Lasiodiplodia theobromae[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Lasionectria krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Malaysiasca phaii	*Freycinetia javanica*	Krabi Province	Tibpromma et al. (2018b)
Massarina pandanicola[a]	*Pandanus* sp.	Chumphon Province	Tibpromma et al. (2018a)
Meyerozyma caribbica[a]	*Pandanus* sp., *Freycinetia* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Montagnula krabiensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Musicillium pandanicola	*Pandanus* sp.	Chiang Mai Province	Tibpromma et al. (2018b)
Mycoleptodiscus endophytic[a]	*Freycinetia* sp.	Ranong Province	Tibpromma et al. (2018a)

Table 7 (continued)

Taxa	Host	Location	References
Neomassarina pandanicola	*Pandanus* sp.	Prachuap Khiri Khan Province	Hyde et al. (2018)
Neooccultibambusa thailandensis	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Neopestalotiopsis chiangmaiensis	*Pandanus* sp.	Chiang Mai Province	Tibpromma et al. (2018b)
Neopestalotiopsis phangngaensis	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Novomicrothelia pandanicola	*Pandanus tectorius*	Chanthaburi Province	Zhang et al. (2017a, b)
Pandanaceomyces krabiensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Parasarcopodium pandanicola	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2016a)
Parascedosporium putredinis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Pestalotiopsis jiangxiensis[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Pestalotiopsis krabiensis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Pestalotiopsis microspora[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Phanerochaete chrysosporium[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Phyllosticta capitalensis[a]	*Pandanus* sp.	Chumphon, Ranong Province	Tibpromma et al. (2018a)
Pseudoachroiostachys krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Pseudochaetosphaeronema pandanicola	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Pseudofusicoccum adansoniae	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Pseudohyaloseta pandanicola	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Pseudoornatispora krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Pseudopithomyces pandanicola	*Pandanus amaryllifolius*	Chiang Rai Province	Tibpromma et al. (2018b)
Roussoella solani	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Sirastachys phangngaensis	*Pandanus* sp.	Phang Nga Province	Tibpromma et al. (2018b)
Terriera pandanicola	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)
Thozetella pandanicola	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Torula ficus	*Pandanus* sp.	Chiang Mai Province	Tibpromma et al. (2018b)
Tubeufia freycinetiae	*Freycinetia javanica*	Phang Nga Province	Tibpromma et al. (2018b)
Tubeufia inaequalis	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Tubeufia pandanicola	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Tubeufia parvispora	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Volutella krabiense	*Pandanus* sp.	Krabi Province	Tibpromma et al. (2018b)
Volutella thailandensis	*Pandanus* sp.	Prachuap Khiri Khan Province	Tibpromma et al. (2018b)

[a]Endophytic fungi

intensively for many decades, but still there are numerous undiscovered species (Blakeman 1981; Dickinson and Preece 1976; Fokkema and van den Heuvel 1986; Carroll 1991; Gilbert and Reynolds 2002, 2005; Wu et al. 2011; Chomnunti et al. 2014; Hyde et al. 2013, 2016; Hongsanan et al. 2014a, 2015a, b, 2017). This is largely because many taxa will not grow in culture as they are biotrophs and thus it is difficult to obtain sequence data (Hongsanan et al. 2014a, 2017). DNA extraction from fresh material has been used as a core solution to this issue, however, fungal epiphytes often grow intermixed with colonies of other species (Chomnunti et al. 2014), and this may lead to contamination problems and difficulties in obtaining appropriate DNA sequence from targeted organisms.

Mostly fungal epiphytes in Thailand have been reported without species-level identification (Athipunyakom and Likhitekaraj 2006). The foliar epiphytes in Thailand have been studied by us since 2008. More than 170 specimens were collected mainly in the north, which included 74 species (Table 1). Of all foliar epiphytes we collected, none are confirmed existing records, nine are new records, 42 are new species (Table 9), and 23 are potentially novel species awaiting description. These 51 described taxa have been shown to belong to Asterinales (8), Capnodiales and Chaetothyriales (26), *incertae sedis* (3), Meliolales (7), Microthyriaceae and Micropeltidaceae (3), Muyocopronales (1), Zeloasperisporiales (3) (Wu et al. 2011; Hongsanan et al. 2014a, b, 2015a, b, c, 2016a, b, 2017; Liu et al. 2015; Ariyawansa et al. 2015; Hyde et al. 2016; Tibpromma et al. 2017b). Thus, 88% of foliar epiphyte species collected are new to science.

Table 8 Species of fungi on *Tectona grandis* mostly reported in northern Thailand (novel species from Thailand are in bold)

Species	References
Alternaria tillandsiae	Doilom et al. (2017a)
Barriopsis tectonae	Doilom et al. (2014)
Barriopsis thailandica	Tibpromma et al.(2017a)
*Berkleasmium talaumae**	Doilom et al. (2017a)
Boerlagiomyces macrosporus	Doilom et al. (2017a)
*Ceratocladium purpureogriseum**	Doilom et al. (2017a)
Chaetomium globosum	Maharachchikumbura et al. (2016)
Diaporthe neoraonikayaporum	Doilom et al. (2017a)
Diaporthe tectonae	Doilom et al. (2017a)
Diaporthe tectonendophytica	Doilom et al. (2017a)
Diaporthe tectonigena	Doilom et al. (2017a)
Diatrypella tectonae	Shang et al. (2017)
Distoseptispora tectonae	Hyde et al. (2016)
Distoseptispora tectonigena	Hyde et al. (2016)
Dothiorella tectonae	Doilom et al. (2015)
Erysiphe mori	Meeboon and Takamatsu (2017)
Erysiphe tectonae	Meeboon and Takamatsu (2017)
Helicoma siamense	Doilom et al. (2017a)
Hermatomyces indicus	Doilom et al. (2017a), Koukol et al. (2018)
Hermatomyces sphaericus	Doilom et al. (2017a), Koukol et al. (2018)
Huntiella chinaeucensis	Maharachchikumbura et al. (2016)
Kirschsteiniothelia tectonae	Li et al. (2016)
Lasiodiplodia brasiliensis	Doilom et al. (2015)
Lasiodiplodia pseudotheobromae	Doilom et al. (2015)
Lasiodiplodia theobromae	Doilom et al. (2015, 2017a)
Longiostiolum tectonae	Li et al. (2016)
Macrovalsaria megalospora	Doilom et al. (2017a)
Manoharachariella tectonae	Doilom et al. (2017a)
Melanoctona tectonae	Tian et al. (2016)
Neocosmospora solani (= *Fusarium solani*)	Doilom et al. (2017a)
Neooccultibambusa chiangraiensis	Doilom et al. (2017a)
Paradictyoarthrinium diffractum	Liu et al. (2015), Doilom et al. (2017a)
Paradictyoarthrinium tectonicola	Liu et al. (2015)
Phaeoacremonium italicum	Doilom et al. (2017a)
Phaeoacremonium tectonae	Ariyawansa et al. (2015)
Phyllosticta capitalensis	Wikee et al. (2013a, b)
Pseudocoleodictyospora sukhothaiensis	Doilom et al. (2017a)
Pseudocoleodictyospora tectonae	Doilom et al. (2017a)
Pseudocoleodictyospora thailandica	Doilom et al. (2017a)
Pseudofusicoccum adansoniae	Doilom et al. (2015)
Pseudomonodictys tectonae	Ariyawansa et al. (2015)
Rhytidhysteron tectonae	Doilom et al. (2017a)
Sphaeropsis eucalypticola	Doilom et al. (2015, 2017a)
Stachybotrys levisporus	Doilom et al. (2017a)
Stachybotrys renisporus	Doilom et al. (2017a)
Subglobosporium tectonae	Doilom et al. (2017a)
Thaxteriellopsis lignicola	Doilom et al. (2017a)
Tubeufia tectonae	Doilom et al. (2017a)

Expected number of new species: > 100

[a]No molecular data available

What about other countries?

One may assume that because Thailand is tropical and was previously poorly studied, we should expect to find a high fungal novelty. However, what is the situation in well-documented countries? We provided some answers to this question by studying the fungi on Rosaceae and *Cornus* in Europe. We show that 76% of species on Rosaceae and 32% on *Cornus* are novel.

Fungi on Rosaceae

Rosaceae is one of the largest families of flowering plants including over 3000 species mostly distributed in the northern hemisphere (Wanasinghe et al. 2018). There are more than 4000 records of fungi on Rosaceae species in the U.S. National Fungus Collections Fungus-Host Database (Wanasinghe et al. 2018), but they are poorly investigated in terms of taxonomic relationships with molecular identification. Fungi on Rosaceae species have been reported in recent studies as saprobes (Dissanayake et al. 2017a; Wanasinghe et al. 2017), endophytes (Salgado-Salazar et al. 2008; Rovná et al. 2015), mycorrhizae (Bzdyk et al. 2016; El-Bashiti et al. 2017) or pathogens (Yan et al. 2015; Deng et al. 2017; Santos et al. 2017; Wang et al. 2017).

The fungi on *Rosa* species have been studied by us since 2013. More than 200 specimens were collected mainly from Italy, Russia, Sweden, UK and Uzbekistan and resulted in 59 novel species, with 15 new host records and three confirmed earlier records (Table 10). Thus, 76% of the fungal species on Rosaceae collected were new to science.

Fungi on *Cornus*

Cornus (dogwood) is a genus of plants in the family Cornaceae. The genus comprises about 58 species, which are widely distributed in temperate and subtropical (rarely tropical) regions of the northern hemisphere, with a rich diversity in eastern Asia, eastern and western North America (Murrell 1993; Fan 2001; Xiang et al. 2006). In addition, some endemic species of *Cornus* are reported from South America and tropical Africa (Fan 2001). Members of *Cornus* are mostly trees and shrubs and rarely perennial herbs with woody rhizomes (Noshiro and Baas 1998; Fan 2001). While approximately 300 fungal species have been reported on *Cornus* species, only few of them have detailed illustrations and descriptions or are verified by DNA sequence data (Petrak 1921, 1925; Saccardo 1898; Senanayake et al. 2015; Wijayawardene et al. 2016). There is no comprehensive account or checklist of fungi on *Cornus*.

The fungi on *Cornus* species have been studied by us since 2015. More than 100 specimens were collected mainly from Italy and Russia, which included 77 species comprising 52 existing species and 25 novel species waiting to be described. Thus, of all fungi collected on *Cornus*, 43 are confirmed as existing records from *Cornus*, and nine are new host records. Therefore, 32% of fungi collected on *Cornus* species are new to science. We predict that with extensive sampling, over 100 novel species will be introduced in the coming years.

Novelty of fungi in Europe

In considering these two examples it seems that the novelty of species in Europe is also surprisingly high. Our other studies on *Clematis* and several other hosts are also showing a remarkably high novel diversity. Hawksworth and Lücking (2017) estimated that there are 2.2–3.8 million fungal species in the world of which only 120,000 are presently known. Our studies appear to confirm these predicted high numbers.

Novel chemistry

Aside from the various taxonomic novelties, numerous new and unique biologically active secondary metabolites were also obtained from fungal species of northern Thailand. A selection of their chemical structures is depicted in Fig. 1. The producer organisms were often found to constitute undescribed species. Although not all new chemical structures have yet been named or their activity studied, the novel antibiotics terpene alkaloids named pyristriatins (Richter et al. 2016) were obtained from the novel species, *Cyathus pyristriatus* (Li et al. 2016) and the rare terpenoid lentinulactam from *Panus subfasciatus* (Hyde et al. 2016). The cytotoxic polyketides of the gymnopalyne type (Thongbai et al. 2013) and the mildly antibiotic deconins (Surup et al. 2015) were obtained from cultures of *Gymnopus* and *Deconica*, respectively, that probably represent new fungal species. The cultivated mushroom *Lepista sordida* (Thongbai et al. 2017b) yielded nudic acid B, and the nematode trapping species *Hohenbuehelia grisea*, produced the novel heterocyclic terpenoid pleurothiazol (Sandargo et al. 2018). Mycelial cultures of *Agaricus subrufescens* (Thongklang et al. 2017) produced the chemotaxonomic marker Blazeisporol A, which was identified as a selective agonist of Liver X Receptor subtype alpha, which offers avenues to the development of the mushroom as a new nutraceutical with chloesterol-lowering activities.

Several new molecules were also obtained from species of Xylariales, which are one of the most creative orders of Ascomycota with respect to secondary metabolites (Helaly

Table 9 Foliar epiphytes reported in Thailand (novel species from Thailand are in bold)

Species	Host	References
Asterina cynometrae	*Cynometra* sp.	Hyde et al. (2016)
Asterina phlogacanthi	*Clinacanthus nutans*	Hyde et al. (2013)
Asterina phoebesicola	*Phoebes costaricanae*	Hongsanan et al. (2014a)
Capnodium coartatum	*Psidium guajava*	Chomnunti et al. (2011)
Capnodium coffeicola	*Coffea* sp.	Hongsanan et al. (2015a)
Ceramothyrium ficus	*Ficus* sp.	Hongsanan et al. (2015b)
Ceramothyrium longivolcaniforme	Unknown	Zeng et al. (2016)
Ceramothyrium thailandicum	*Lagerstroemia* sp.	Chomnunti et al. (2012a)
Chaetocapnodium siamense	Unknown	Liu et al. (2015)
Chaetothyrina artocarpi	*Artocarpus heterophyllus*	Hyde et al. (2017)
Chaetothyrina guttulata	*Mangifera indica*	Hongsanan et al. (2016a)
Chaetothyrina mangiferae	*Mangifera indica*	Singtripop et al. (2016)
Chaetothyrina musarum	*Musa* sp.	Singtripop et al. (2016)
Chaetothyrium bischofiicola	*Bischofia javanica*	Chomnunti et al. 2012a
Chaetothyriothecium elegans	*Castanopsis* sp.	Hongsanan et al. (2014b)
Conidiocarpus philippinensis	Arecaceae sp.	Liu et al. (2015)
Conidiocarpus plumeriae	*Plumeria* sp.	Hongsanan et al. (2015a)
Discopycnothyrium palmae	*Palm* sp.	Hongsanan et al. (2017)
Irenopsis crotonicola	*Croton persimilis*	Zeng et al. (2018a)
Irenopsis walsurae	*Walsura tubulata*	Hongsanan et al. (2015b)
Lembosia albersii	*Unknown*	Hongsanan et al. (2014a)
Lembosia xyliae	*Xylia* sp.	Ariyawansa et al. (2015)
Leptoxyphium cacuminum	*Gossypium herbaceum*	Chomnunti et al. (2011)
Meliola citri-maximae	*Citrus maxima*	Hyde et al. (2016)
Meliola clerodendri-infortunati	*Clerodendrum infortunatum*	Hyde et al. (2017)
Meliola clerodendricola	*Clerodendrum* sp.	Hyde et al. (2017)
Meliola mucunicola	*Mucuna pruriens*	Hongsanan et al. (2015c)
Meliola tamarindi	*Tamarindus indica*	Liu et al. (2015)
Meliola thailandicum	*Dimocarpus longan*	Hongsanan et al. (2015c)
Meliola thailandicum	*Acacia auriculiformis*	Hongsanan et al. (2015c)
Micropeltis dendrophthoes	*Dendrophthoe* sp.	Hongsanan et al. (2015b)
Muyocopron lithocarpi	*Lithocarpus lucidus*	Mapook et al. (2016)
Parameliola acaciae	*Acacia auriculiformis*	Li et al. (2016)
Parameliola dimocarpi	*Dimocarpus longan*	Li et al. (2016)
Phaeosaccardinula ficus	*Ficus* sp.	Chomnunti et al. (2012a)
Phragmocapnias asiaticus	*Coffea arabica*	Chomnunti et al. (2011)
Phragmocapnias philippinensis	Arecaceae sp.	Liu et al. (2015)
Phragmocapnias siamensis	*Mangifera indica*	Chomnunti et al. (2011)
Scorias mangiferae	*Mangifera* sp.	Hongsanan et al. (2015b)
Translucidithyrium thailandicum	*Syzygium levinei*	Zeng et al. (2018b)
Trichomerium bambusae	Poaceae sp.	Hyde et al. (2016)
Trichomerium deniqulatum	*Psidium guajava*	Chomnunti et al. (2012b)
Trichomerium foliicola	*Murraya paniculata*	Chomnunti et al. (2012b)
Trichomerium gloeosporum	*Ficus* sp.	Chomnunti et al. (2012b)
Trichomerium gloeosporum	*Gardenia* sp.	Hongsanan et al. (2016c)
Trichomerium siamense	*Tecoma* sp.	Liu et al. (2015)
Trichopeltina asiatica	*Strobilanthes* sp.	Hongsanan et al. (2014c)
Tumidispora shoreae	*Shorea* sp.	Ariyawansa et al. (2015)
Zeloasperisporium ficicola	*Ficus benjamina*	Hongsanan et al. (2015d)
Zeloasperisporium siamense	*Unknown*	Hongsanan et al. (2015d)
Zeloasperisporium wrightiae	*Wrightia religiosa*	Hongsanan et al. (2015d)

Expected number of new species: > 100

Table 10 Species of fungi on Rosaceae reported in the northern hemisphere (novel species are in bold)

Species	Host	References
Alternaria doliconidium	*Rosa canina*	Wanasinghe et al. (2018)
Alternaria hampshirensis	*Rosa* sp.	Wanasinghe et al. (2018)
Amandinea punctata[a]	*Rosa* sp.	Wanasinghe et al. (2018)
Angustimassarina quercicola[a]	*Rosa canina*	Wanasinghe et al. (2018)
Angustimassarina rosarum	*Rosa canina*	Wanasinghe et al. (2018)
Bartalinia rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Bhatiellae rosae	*Rosa canina*	Wanasinghe et al. (2018)
Broomella rosae	*Rosa canina*	Wanasinghe et al. (2018)
Coelodictyosporium rosarum	*Rosa* sp.	Wanasinghe et al. (2018)
Comoclathris rosae	*Rosa canina*	Wanasinghe et al. (2018)
Comoclathris rosarum	*Rosa canina*	Wanasinghe et al. (2018)
Comoclathris rosigena	*Rosa canina*	Wanasinghe et al. (2018)
Coniochaeta baysunika	*Rosa* sp.	Wanasinghe et al. (2018)
Coniochaeta rosae	*Rosa hissarica*	Wanasinghe et al. (2018)
Dematiopleospora rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Diaporthe eres[a]	*Rosa* sp.	Wanasinghe et al. (2018)
Diaporthe foeniculina[a]	*Rosa canina*	Wanasinghe et al. (2018)
Diaporthe rhusicola[a]	*Rosa canina*	Wanasinghe et al. (2018)
Diaporthe rosae	*Rosa* sp.	Wanasinghe et al. (2018)
Diaporthe rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Diaporthe rudis[a]	*Rosa canina*	Wanasinghe et al. (2018)
Diplodia seriata[a]	*Rosa canina*	Wanasinghe et al. (2018)
Endoconidioma rosae-hissaricae	*Rosa hissarica*	Wanasinghe et al. (2018)
Epicoccum rosae	*Rosa canina*	Wanasinghe et al. (2018)
Keissleriella rosacearum	*Rosa canina*	Wanasinghe et al. (2018)
Keissleriella rosae	*Rosa canina*	Wanasinghe et al. (2018)
Keissleriella rosarum	*Rosa canina*	Wanasinghe et al. (2018)
Lasiodiplodia theobromae[a]	*Rosa canina*	Wanasinghe et al. (2018)
Lecidella elaeochroma[a]	*Rosa canina*	Wanasinghe et al. (2018)
Lophiostoma rosae	*Rosa* sp.	Wanasinghe et al. (2018)
Marjia tianschanica	*Rosa canina*	Wanasinghe et al. (2018)
Marjia uzbekistanica	*Cerasus tianschanica*	Wanasinghe et al. (2018)
Melanodiplodia tianschanica	*Rosa ecae*	Wanasinghe et al. (2018)
Monoseptella rosae	*Rosa* sp.	Wanasinghe et al. (2018)
Muriformistrickeria rosae	*Rosa canina*	Wanasinghe et al. (2018)
Muriformistrickeria rubi[a]	*Rosa canina*	Wanasinghe et al. (2018)
Murilentithecium rosae	*Rosa canina*	Wanasinghe et al. (2018)
Neoascochyta rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Neoconiothyrium rosae	*Rosa canina*	Wanasinghe et al. (2018)
Neofusicoccum australe[a]	*Rosa* sp.	Wanasinghe et al. (2018)
Neopaucispora rosaecae	*Rosa ecae*	Wanasinghe et al. (2018)
Neosetophoma rosarum	*Rosa canina*	Wanasinghe et al. (2018)
Neosetophoma rosigena	*Rosa canina*	Wanasinghe et al. (2018)
Paraconiothyrium rosae	*Rosa canina*	Wanasinghe et al. (2018)
Paraphaeosphaeria michotii[a]	*Rosa canina*	Wanasinghe et al. (2018)
Paraphaeosphaeria rosae	*Rosa canina*	Wanasinghe et al. (2018)
Paraphaeosphaeria rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Pararoussoella rosarum	*Rosa* sp.	Wanasinghe et al. (2018)

Table 10 (continued)

Species	Host	References
Parathyridaria rosae	*Rosa* sp.	Wanasinghe et al. (2018)
Paraxylaria rosacearum	*Rosa* sp.	Wanasinghe et al. (2018)
Phragmocamarosporium rosae	*Rosa canina*	Wanasinghe et al. (2018)
Pleospora rosae	*Rosa canina*	Wanasinghe et al. (2018)
Pleospora rosae-caninae	*Rosa canina*	Wanasinghe et al. (2018)
Pleurophoma pleurospora[a]	*Rosa* sp.	Wanasinghe et al. (2018)
Poaceicola rosae	*Rosa canina*	Wanasinghe et al. (2018)
Populocrescentia rosae	*Rosa hissarica*	Wanasinghe et al. (2018)
Pseudocercospora rosae	*Rosa canina*	Wanasinghe et al. (2018)
Pseudopithomyces rosae	*Rosa canina*	Wanasinghe et al. (2018)
Pseudostrickeria rosae	*Rosa canina*	Wanasinghe et al. (2018)
Sclerostagonospora rosae	*Rosa* sp.	Wanasinghe et al. (2018)
Sclerostagonospora rosicola	*Rosa* sp.	Wanasinghe et al. (2018)
Seimatosporium rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Seimatosporium rosigenum	*Rosa canina*	Wanasinghe et al. (2018)
Seiridium rosarum	*Rosa canina*	Wanasinghe et al. (2018)
Sigarispora caulium[a]	*Rosa canina*	Wanasinghe et al. (2018)
Sigarispora rosicola	*Rosa* sp.	Wanasinghe et al. (2018)
Sporormurispora pruni	*Prunus erythrocarpa*	Wanasinghe et al. (2018)
Suttonomyces rosae	*Rosa canina*	Wanasinghe et al. (2018)
Teichospora rubriostiolata[a]	*Rosa multibracteata*	Wanasinghe et al. (2018)
Uzbekistanica rosae-hissaricae	*Rosa hissarica*	Wanasinghe et al. (2018)
Uzbekistanica yakutkhanika	*Rosa hissarica*	Wanasinghe et al. (2018)
Wojnowicia rosicola	*Rosa canina*	Wanasinghe et al. (2018)
Xenomassariosphaeria rosae	*Rosa canina*	Wanasinghe et al. (2018)

Expected number of new species: > 100

[a]New host records

et al. 2018). As an example, the lenormandins (Kuhnert et al. 2015) constitute highly specific pigments of the stromata of the *Hypoxylon lenormandii* complex. Work on the secondary metabolism of fungi from northern Thailand is ongoing, and papers on additional new and interesting molecules are in preparation. For instance, even other groups of Ascomycota including the Diaporthales that are treated above, are also well-known to be extremely creative secondary metabolite producers (Chepkirui and Stadler 2017).

Potential future avenues

For decades, mycologists have estimated fungal species numbers using various criteria. Such estimates have ranged from 500,000 to almost 10 million species, with mycologists generally agreeing on 1.5–5 million (Hawksworth 1991; Hawksworth and Lücking 2017). In the most recent estimates, Hawksworth and Lücking (2017) suggested between 2.2 and 3.8 million fungal species and that only 120,000 (8%) have been described. Hyde (2001) suggested that the 'missing fungi' might be found in poorly studied countries and hosts, or poorly studied habitats or niches. Tedersoo et al. (2014) used DNA metabarcoding data from hundreds of globally distributed soil samples, and demonstrated that climatic factors, followed by edaphic and spatial variables constituted the best predictors of fungal richness and community composition at the global scale. Tedersoo et al. (2017) provided phylogenetic placement and principal niche analysis for > 40 previously unrecognized fungal groups from global soil samples at the order and class level based on combined 18S (nSSU) and 28S (nLSU) rRNA gene sequences, and showed that within the fungal kingdom, tropical and non-tropical habitats were equally likely to harbor novel groups.

In this paper, we have provided an insight to show where missing fungi could be found. From data accumulated to date, and with randomized sampling only in northern Thailand, the fungal diversity with new species recovered far exceeds our expectations. We should revisit

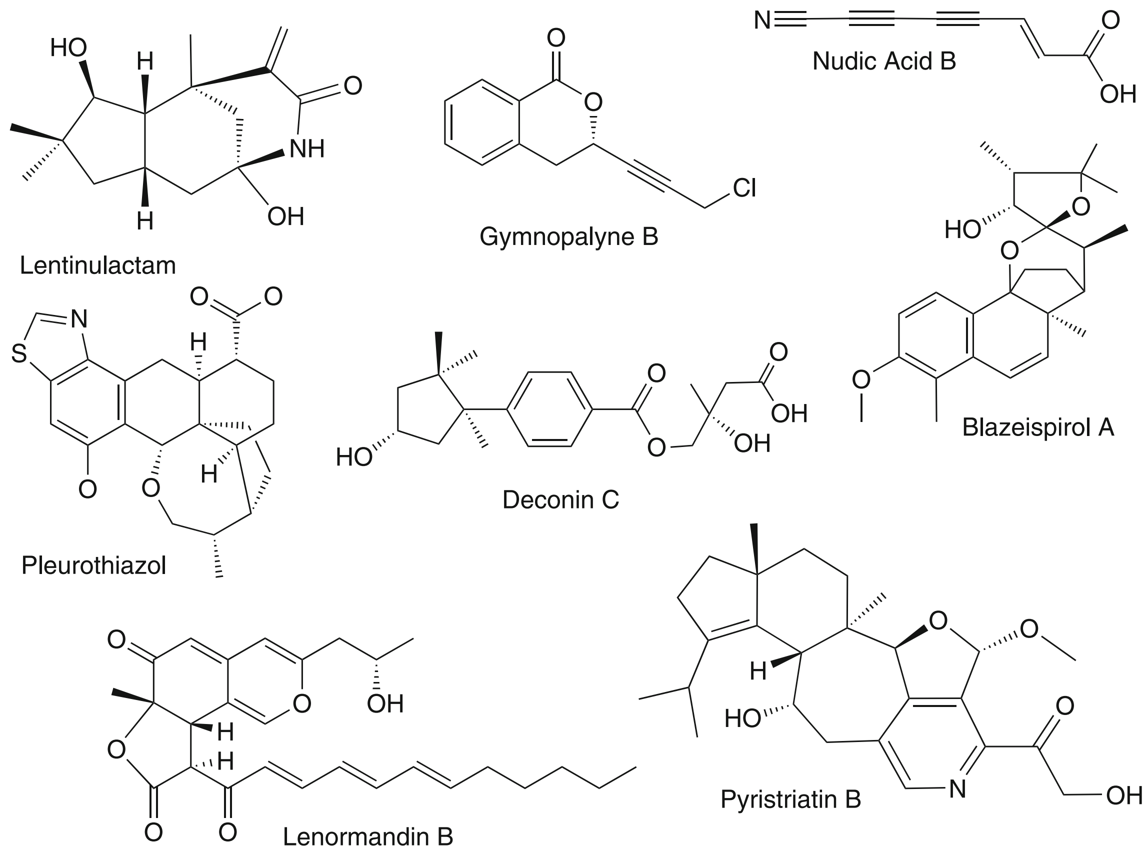

Fig. 1 Chemical structures of selected biologically active secondary metabolites from Thai fungi

our current sampling strategies to target more novel species and similar studies could be extended to other parts of Thailand and surrounding countries. For some groups, the proportion of new species from samples collected is well above 50%, but this number might still be an underestimate because we assume we have still understudied the areas in which we have collected the material. Our studies on speciose genera, such as *Colletotrichum* and *Pestalotiopsis* have revealed many new species and this means that despite the high number of already described species, there is still much to be discovered. Tibpromma et al. (2018) recovered novel cultured endophytic species from Pandanaceae, but certainly there are unculturable orphan fungal species, that could represent a reservoir of novel species with a panoply of unexploited bioactive compounds. How will this impact on our anticipated number of fungi? Possibly we can argue that previously simple blind sampling strategies and inadequate DNA sequence analyses, limit new species discovery. Our studies in northern Thailand have revealed more new species as the taxonomic assessment methods used became more reliable and substrates/environments sampled were strategic. There are obviously other major fungal groups that warrant investigation (e.g. aquatic fungi, entomopathogens, dung fungi, edible mushrooms, mycorrizhae, and wood decay fungi) that are globally distributed, but poorly sampled in Thailand. There is a need to further sample unexplored habitats (e.g. extreme environments) and substrata. One research area that we have yet to incorporate is sequence-based fungal community analyses. This will undoubtedly reveal and unravel an astonishing diversity of novel species, but as OTUs (Hongsanan et al. 2018). The major research challenges, however, to decipher fungal diversity in largely unexplored regions require more personnel to undertake multifaceted approaches to recover, identify and conserve the potentially new species waiting to be discovered.

Conclusion

Huge advances have been made in the understanding of the fungi in northern Thailand using polyphasic approaches and considerable advances in arranging the classification of fungi at the higher levels (cf. Tedersoo et al. 2018) have been concluded. Many novel fungi have been inventoried for the region, but much work remains. For example, many more species in the edible genus *Agaricus* await description. In these relatively well known mushroom genera we are finding that more than 93% of species collected are new to science. In the microfungi which appear to be relatively poorly studied, the percentage does not appear to be as high. The studied regions mainly includes three provinces in northern Thailand. The southern, eastern and central provinces of Thailand and surrounding countries of Cambodia, Myanmar, Laos and Vietnam have barely been studied for fungi and thus we predict that there are huge numbers of new species waiting to discovered in this region. At the same time, we have been finding ways to exploit these fungi. Our work has resulted in the discovery of at least ten new species which are being developed as novel industrial mushrooms. We have also isolated at least ten novel medicinal compounds from Thai fungi and are also looking at ways to exploit them in biocontrol. All of the fungi mentioned above are known to produce various therapeutic metabolites with high biological activities. It is therefore very important to properly characterize not only these compounds, but to carefully resolve the species names, so that researchers can better identify and screen potential taxa for future biotechnological applications. Fungi have been poorly exploited and yet have a huge potential in biocontrol, bioremediation, novel compound discovery as well as basic industrial organisms as edible mushrooms, fertilizers and cosmetics. With such high novelty, there is a need for extensive research to exploit the biotechnological potential of these fungi.

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References

Abiala MA, Popoola OO, Olawuyi OJ, Oyelude JO, Akanmu AO, Killani AS, Osonubi O, Odebode AC (2013) Harnessing the potentials of vesicular arbuscular mycorrhizal (VAM) fungi to plant growth—a review. Int J Pure Appl Sci Technol 14:61–79

Ariyawansa HA, Hyde KD, Jayasiri SC, Buyck B, Chethana KWT, Dai DQ, Dai YC, Daranagama DA, Jayawardena RS, Lücking R, Ghobad-Nejhad M, Niskanen T, Thambugala KM, Voigt K, Zhao RL, Li GJ, Doilom M, Boonmee S, Yang ZL, Cai Q, Cui YY, Bahkali AH, Chen J, Cui BK, Chen JJ, Dayarathne MC, Dissanayake AJ, Ekanayaka AH, Hashimoto A, Hongsanan S, Jones EBG, Larsson E, Li WJ, Li QR, Liu JK, Luo ZL, Maharachchikumbura SSN, Mapook A, McKenzie EHC, Norphanphoun C, Konta S, Pang KL, Perera RH, Phookamsak R, Phukhamsakda C, Pinruan U, Randrianjohany E, Singtripop C, Tanaka K, Tian CM, Saowaluck Tibpromma, Abdel-Wahab Mohamed A, Wanasinghe Dhanushka N, Wijayawardene Nalin N, Zhang JF, Zhang H, Abdel-Aziz FA, Wedin M, Westberg M, Ammirati JF, Bulgakov Timur S, Lima DX, Callaghan TM, Callac P, Chang CH, Coca LF, Dal-Forno M, Dollhofer V, Fliegerová K, Greiner K, Griffith GW, Ho HM, Hofstetter V, Jeewon R, Kang JC, Wen TC, Kirk PM, Kytövuori I, Lawrey JD, Xing J, Li H, Liu ZY, Liu XZ, Liimatainen K, Lumbsch TH, Matsumura M, Moncada B, Nuankaew S, Parnmen S, Santiago ALCMDA, Sommai S, Song Y, de Souza CAF, de Souza-Motta CM, Su HY, Suetrong S, Wang Y, Wei SF, Yuan HS, Zhou LW, Réblová M, Fournier J, Camporesi E, Luangsa-ard JJ, Tasanathai K, Khonsanit A, Thanakitpipattana D, Somrithipol S, Diederich P, Millanes AM, Common RS, Stadler M, Yan JY, Li XH, Lee HW, Nguyen TTT, Lee HB, Battistin E, Marsico O, Vizzini A, Vila J, Ercole E, Eberhardt U, Simonini G, Wen HA, Chen XH, Miettinen O, Spirin V, Hernawati H (2015) Fungal diversity notes 111–252—taxonomic and phylogenetic contributions to fungal taxa. Fungal Divers 75:27–274

Athipunyakom P, Likhitekaraj S (2006) Plant pathogenic Ascomycetes fungi on fruit trees. In: Proceedings of 44th Kasetsart University annual conference, pp 762–770

Bashir H, Hussain S, Khalid AN, Khan Niazi AR, Parra L, Callac P (2018) First report of *Agaricus* sect. *Brunneopicti* from Pakistan with descriptions of two new species. Phytotaxa 357:167–178

Blakeman JP (1981) Microbial ecology of the phyllosphere. Academic Press, London

Bucher VVC, Hyde KD, Pointing SB, Reddy CA (2004) Production of wood decay enzymes, mass loss and lignin solubilization in wood by marine ascomycetes and their anamorphs. Fungal Divers 15:1–14

Bzdyk RM, Kohler J, Olchowik J, Aleksandrowicz-Trzcińska M, Kirisits T (2016) Arum-type of arbuscular mycorrhizae, dark septate endophytes and *Olpidium* spp. In fine roots of container-grown seedlings of *Sorbus torminalis* (Rosaceae). Acta Soc Bot Pol 85:1–12

Cai L, Hyde KD, Taylor PWJ, Weir BS, Waller J, Abang MM, Zhang JZ, Yang YL, Phoulivong S, Liu ZY, Prihastuti H, Shivas RG, McKenzie EHC, Johnston PR (2009) A polyphasic approach for studying *Colletotrichum*. Fungal Divers 39:183–204

Cai L, Udayanga D, Manamgoda DS, Maharachchikumbura SSN, McKenzie EHC, Guo LD, Liu XZ, Bahkali AH, Hyde KD (2011) The need to carry out re-inventory of plant pathogenic fungi. Trop Plant Pathol 36:205–213

Cannon PF, Damm U, Johnston PR, Weir BS (2012) *Colletotrichum* current status and future directions. Stud Mycol 73:181–213

Carroll GC (1991) Beyond pest deterrence-alternative strategies and hidden costs of endophytic mutualisms in vascular plants. In: Andrews JH, Hirano SS (eds) Microbial ecology of leaves. Springer, New York, pp 358–375

Chandrasrikul A, Suwanarit P, Sangwanit U, Lumyong S, Payapanon A, Sanoamuang N, Pukahuta C, Petcharat V, Sardsud U, Duengkae K, Klinhom U (2011) Checklist of mushrooms (Basidiomycetes) in Thailand. Office of Natural Resources and Environmental Policy and Planning, Bangkok, p 448

Chareprasert S, Piapukiew J, Thienhirun S, Whalley AJS, Sihanonth P (2006) Endophytic fungi of teak leaves *Tectona grandis* L. and rain tree leaves *Samanea saman* Merr. World J Microbiol Biotechnol 22:481–486

Chen J, Zhao RL, Karunarathna SC, Callac P, Raspé O, Bahkali AH, Hyde KD (2012) *Agaricus megalosporus*: a new species in section Minores. Cryptogam, Mycol 33:145–155

Chen J, Zhao R, Parra LA, Guelly AK, De Kesel A, Rapior S, Hyde KD, Chukeatirote E, Callac P (2015) *Agaricus* section

Brunneopicti: a phylogenetic reconstruction and emendation with commentary on taxa. Phytotaxa 192:145–168
Chen J, Parra LA, De Kesel A, Khalid AN, Qasim T, Ashraf A, Bahkali AH, Hyde KD, Zhao R, Callac P (2016) Inter– and intra–specific diversity in *Agaricus endoxanthus* and allied species reveals a new taxon, *A. punjabensis*. Phytotaxa 252:1–16
Chen J, Callac P, Parra LA, Karunarathna SC, He MQ, Moinard M, De Kesel A, Raspé O, Wisitrassameewong K, Hyde KD, Zhao RL (2017) Study in *Agaricus* subgenus *Minores* and allied clades reveals a new American subgenus and contrasting phylogenetic patterns in Europe and Greater Mekong Subregion. Persoonia 38:170–196
Chepkirui C, Stadler M (2017) The genus *Diaporthe*: a rich source of diverse and bioactive metabolites. Mycol Progr 16:477–494
Chomnunti P, Schoch CL, Aguirre-Hudson B, Ko-Ko TW, Hongsanan S, Jones EBG, Kodsueb R, Phookamsak R, Chukeatirote E, Bahkali AH, Hyde KD (2011) Capnodiaceae. Fungal Divers 51:103–134
Chomnunti P, Ko TWK, Chukeatirote E, Hyde KD, Cai L, Jones EB, Kodsueb R, Hassan BA, Chen H (2012a) Phylogeny of Chaetothyriaceae in northern Thailand including three new species. Mycologia 104:382–395
Chomnunti P, Bhat DJ, Jones EGB, Chukeatirote E, Bahkali AH, Hyde KD (2012b) Trichomeriaceae, a new sooty mould family of Chaetothyriales. Fungal Divers 56:63–76
Chomnunti P, Hongsanan S, Aguirre-Hudson B, Tian Q, Peršoh D, Dhami MK, Alias AS, Xu J, Liu X, Stadler M, Hyde KD (2014) The sooty moulds. Fungal Divers 66:1–36
Crouch JA (2014) *Colletotrichum caudatum* s.l. is a species complex. IMA Fungus 5:1–30
Cui YY, Cai Q, Tang LP, Liu JW, Yang ZL (2018) The family Amanitaceae: molecular phylogeny, higher-rank taxonomy and the species in China. Fungal Divers 91:5–230
Dai RC, Li GJ, He MQ, Liu RL, Ling ZL, Wu JR, Zhao RL (2016) Characterization of four species including one new species of *Agaricus* subgenus *Spissicaules* from Eastern China. Mycosphere 7:405–416
Damm U, Cannon PF, Woudenberg JHC, Johnston PR, Weir BS, Tan YP, Shivas RG, Crous PW (2012) The *Colletotrichum boninense* species complex. Stud Mycol 73:1–36
Damm U, Sato T, Alizadeh A, Groenewals JZ, Crous PW (2019) The *Colletotrichum dracaenophilum*, *C. magnum* and *C. orchidearum* speices complexes. Stud Mycol 92:1–46
Daranagama DA, Hyde KD, Sir EB, Thambugala KM, Tian Q, Samarakoon MC, McKenzie EH, Jayasiri SC, Tibpromma S, Bhat JD, Liu X (2018) Towards a natural classification and backbone tree for Graphostromataceae, Hypoxylaceae, Lopadostomataceae and Xylariaceae. Fungal Divers 88:1–165
Deng CH, Plummer KM, Jones DA, Mesarich CH, Shiller J, Taranto AP, Robinson AJ, Kastner P, Hall NE, Templeton MD, Bowen JK (2017) Comparative analysis of the predicted secretomes of Rosaceae scab pathogens *Venturia inaequalis* and *V. pirina* reveals expanded effector families and putative determinants of host range. BMC Genomics 18:339
Diao YZ, Zhang C, Liu F, Wang WZ, Cai L, Liu XL (2017) *Colletotrichum* species causing anthracnose disease of chili in China. Persoonia 38:20–37
Dickinson CH, Preece TF (1976) Microbiology of aerial plant surfaces. Academic Press, London
Dissanayake AJ, Liu M, Zhang W, Chen Z, Udayanga D, Chukeatirote E, Li X, Yan J, Hyde KD (2015) Morphological and molecular characterization of *Diaporthe* species associated with grapevine trunk disease in China. Fungal Biol 119:283–294
Dissanayake AJ, Camporesi E, Hyde KD, Wei Z, Yan JY, Li XH (2017a) Molecular phylogenetic analysis reveals seven new *Diaporthe* species from Italy. Mycosphere 8:853–877
Dissanayake AJ, Phillips AJL, Hyde KD, Yan JY, Li XH (2017b) The current status of species in *Diaporthe*. Mycosphere 8:1106–1156
Dissanayake AJ, Zhang W, Liu M, Hyde KD, Zhao WS, Li XH, Yan JY (2017c) *Diaporthe* species associated with peach tree dieback in Hubei, China. Mycosphere 8:533–549
Doilom M, Shuttleworth L, Roux J, Chukeatirote E, Hyde KD (2014) *Barriopsis tectonae* sp. nov. a new species of Botryosphaeriaceae from *Tectona grandis* (teak) in Thailand. Phytotaxa 176:081–091
Doilom M, Shuttleworth L, Roux J, Chukeatirote E, Hyde KD (2015) Botryosphaeriaceae associated with *Tectona grandis* (teak) in northern Thailand. Phytotaxa 233:001–026
Doilom M, Taylor JE, Bhat DJ, Chukeatirote E, Hyde K, To-Anun C, Jones E (2016) Checklist of fungi on teak. Mycosphere 7:656–678
Doilom M, Dissanayake AJ, Wanasinghe DN, Boonmee S, Liu JK, Bhat DJ, Taylor JE, Bahkali AH, McKenzie EH, Hyde KD (2017a) Microfungi on *Tectona grandis* (teak) in northern Thailand. Fungal Divers 82:107–182
Doilom M, Manawasinghe IS, Jeewon R, Jayawardena RS, Tibpromma S, Hongsanan S, Meepol W, Lumyong S, Jones EBG, Hyde KD (2017b) Can ITS sequence data identify fungal endophytes from cultures? A case study from *Rhizophora apiculata*. Mycosphere 8:1869–1892
El-Bashiti TA, El-Kichaoui A, Ajwa AHA (2017) Evaluation the effect of ectomycorrhizal fungi on *Prunus cerasifera* × *salicina* (Rosaceae) growth compared with chemical and organic fertilizer. Sky J Agric Res 6:41–49
Fan C (2001) Phylogenetic relationships within *Cornus* (Cornaceae) based on 26S rDNA sequences. Am J Bot 88:1131–1138
Fokkema NJ, van den Heuvel J (1986) Microbiology of the phyllosphere. Springer-Verlag, New York
Fry WE, McGrath MT, Seaman A, Zitter TA, McLeod A, Danies G, Small IM, Myers K, Everts K, Gevens AJ, Gugino BK (2013) The 2009 late blight pandemic in the eastern United States–causes and results. Plant Dis 97:296–306
Gadd G, Watkinson SC, Dyer PS (2007) Fungi in the environment. Cambridge University Press, Cambridge
Giatgong P (1980) Host index of plant diseases in Thailand, 2nd edn. Mycology Branch, Plant Pathology and Microbiology Division, Department of Agriculture and Cooperatives, Bangkok. http://nt.ars-grin.gov/fungaldatabases
Gilbert G, Reynolds DR (2002) The ecology of foliicolous fungi. In: Ryvarden L (ed) Proceedings of the 7th international mycological congress, Oslo, Norway, p 89
Gilbert G, Reynolds DR (2005) Epifoliar fungi from Queensland, Australia. Aust Syst Bot 18:265–289
Goh TK, Hyde KD, Ho WH (1999) A revision of the genus *Dictyosporium*, with descriptions of three new species. Fungal Divers 2:65–100
Gostinčar C, Zajc J, Lenassi M, Plemenitaš A, de Hoog S, Al-Hatmi AMS, Gunde-Cimerman N (2018) Fungi between extremotolerance and opportunistic pathogenicity on humans. Fungal Divers. https://doi.org/10.1007/s13225-018-0414-8
Gui Y, Zhu GS, Callac P, Hyde KD, Parra LA, Chen J, Yang TJ, Huang WB, Gong GL, Liu ZY (2015) *Agaricus* section *Arvenses*: three new species in highland subtropical Southwest China. Fungal Biol 119:79–94
Hawksworth DL (1991) The fungal dimension of biodiversity: magnitude, significance, and conservation. Mycol Res 95:641–655
Hawksworth DL, Lücking R (2017) Fungal diversity revisited: 2.2 to 3.8 million Species. Microbiol Spectr 5:FUNK-0052-2016
He M, Zhao RL (2015) A new species of *Agaricus* section *Minores* from China. Mycology 6:182–186

He MQ, Chen J, Zhou JL, Ratchadawan C, Hyde KD, Zhao RL (2017) Tropic origins, a dispersal model for saprotrophic mushrooms in *Agaricus* section *Minores* with descriptions of sixteen new species. Sci Rep 7:5122

He MQ, Chuankid B, Hyde KD, Cheewangkoon R, Zhao RL (2018a) A new section and species of *Agaricus* subgenus *Pseudochitonia* from Thailand. MycoKeys 40:53–67

He MQ, Hyde KD, Wei SL, Xi YL, Cheewangkoon R, Zhao RL (2018b) Three new species of *Agaricus* section *Minores* from China. Mycosphere 9:189–201

Helaly SE, Richter C, Thongbai B, Hyde KD, Stadler M (2016) Lentinulactam, a hirsutane sesquiterpene with an unprecedented lactam modification. Tetrahedron Lett 57:5911–5913

Helaly SE, Thongbai B, Stadler M (2018) Diversity of biologically active secondary metabolites from endophytic and saprotrophic fungi of the ascomycete order Xylariales. Nat Prod Rep 35:992–1014

Hongo T (1957) Notes on Japanese larger fungi (11). J Jap Bot 32:208–214

Hongsanan S, Li YM, Liu JK, Hofmann T, Piepenbring M, Bhat JD, Boonmee S, Doilom M, Singtripop C, Tian Q, Mapook A (2014a) Revision of genera in Asterinales. Fungal Divers 68:1–68

Hongsanan S, Chomnunti P, Crous PW, Chukeatirote E, Hyde KD (2014b) Introducing *Chaetothyriothecium*, a new genus of Microthyriales. Phytotaxa 161:157–164

Hongsanan S, Bahkali AH, McKenzie EHC, Chukeatirote E, Hyde KD (2014c) Trichopeltinaceae (Dothideomycetes), an earlier name for Brefeldiellaceae, with a new species of *Trichopeltina*. Phytotaxa 176:270–282

Hongsanan S, Tian Q, Hyde KD, Chomnunti P (2015a) Two new species of sooty moulds, *Capnodium coffeicola* and *Conidiocarpus plumeriae* in Capnodiaceae. Mycosphere 6:814–824

Hongsanan S, Hyde KD, Bahkali AH, Camporesi E, Chomnunti P, Ekanayaka H, Gomes AA, Hofstetter V, Jones EG, Pinho DB, Pereira OL (2015b) Fungal Biodiversity Profiles 11 – 20. Cryptogam, Mycol 36:355–380

Hongsanan S, Tian Q, Peršoh D, Zeng XU, Hyde KD, Chomnunti P, Boonmee S, Bahkali AH, Wen TC (2015c) Meliolales. Fungal Divers 74:91–141

Hongsanan S, Tian Q, Bahkali AH, Yang JB, McKenzie EH, Chomnunti P, Hyde KD (2015d) Zeloasperisporiales ord. nov., and two new species of *Zeloasperisporium*. Cryptogam, Mycol 36:301–317

Hongsanan S, Bahkali AH, Chomnunti P, Liu JK, Yang JB, Hyde KD (2016a) *Discopycnothyrium* gen. nov. (Asterinaceae). Mycotaxon 131:859–869

Hongsanan S, Sánchez-Ramírez S, Crous PW, Ariyawansa HA, Zhao RL, Hyde KD (2016b) The evolution of fungal epiphytes. Mycosphere 7:1690–1712

Hongsanan S, Tian Q, Hyde KD, Hu DM (2016c) The asexual morph of *Trichomerium gloeosporum*. Mycosphere 7(9):1473–1479

Hongsanan S, Zhao RL, Hyde KD (2017) A new species of *Chaetothyrina* on branches of mango, and introducing Phaeothecoidiellaceae fam. nov. Mycosphere 8:137–146

Hongsanan S, Jeewon R, Purahong W, Xie N, Liu JK, Jayawardena RS, Ekanayaka AH, Dissanayake A, Raspé O, Hyde KD, Stadler M (2018) Can we use environmental DNA as holotypes? Fungal Divers 92(1):1–30

Hyde KD (1991) *Phomopsis mangrovei*, from intertidal prop roots of *Rhizophora* spp. Mycol Res 95:1149–1151

Hyde KD (2001) Where are the missing fungi? Does Hong Kong have any answers? Mycol Res 105:1514–1518

Hyde KD, Cai L, Cannon PF, Crouch JA, Crous PW, Damm U, Goodwin PH, Chen H, Johnston PR, Jones EBG, Liu ZY (2009) *Colletotrichum*—names in current use. Fungal Divers 39:147–182

Hyde KD, Bahkali AH, Moslem MA (2010) Fungi–an unusual source for cosmetics. Fungal Divers 43:1–9

Hyde KD, Jones EBG, Liu JK, Ariyawansa H, Boehm E, Boonmee S, Braun U, Chomnunti P, Crous PW, Dai DQ, Diederich P, Dissanayake A, Doilom M, Doveri F, Hongsanan S, Jayawardena R, Lawrey JD, Li YM, Liu YX, Lücking R, Monka J, Muggia L, Nelsen MP, Pang KL, Phookamsak R, Senanayake IC, Shearer CA, Suetrong S, Tanaka K, Thambugala KM, Wijayawardene NN, Wikee S, Wu HX, Zhang Y, Begona AH, Alias SA, Aptroot A, Bahkali AH, Bezerra JL, Bhat DJ, Camporesi E, Chukea E, Gueidan C, Hawksworth DL, Hirayama K, Hoog SD, Kang JK, Knudsen K, Li WJ, Li XH, Liu ZY, Mapook A, Mckenzie EHC, Miller AN, Mortimer PE, Phillips AJL, Raja HA, Scheuer C, Schumm F, Taylor JE, Tian Q, Tibpromma S, Wanasinghe DN, Wang Y, Xu JC, Yacharoen S, Yan JY, Zang M (2013) Families of Dothideomycetes. Fungal Divers 63:1–313

Hyde KD, Nilsson RH, Alias SA, Ariyawansa HA, Blair JE, Cai L, de Cock AWAM, Dissanayake AJ, Glockling SL, Goonasekara ID, Gorczak M, Hahn M, Jayawardena RS, van Kan JAL, Laurence MH, Lévesque CA, Li XH, Liu JK, Maharachchikumbura SSN, Manamgoda DS, Martin FN, McKenzie EHC, McTaggart AR, Mortimer PE, Nair PVR, Pawłowska J, Rintoul TL, Shivas RG, Spies CFJ, Summerell BA, Taylor PWJ, Terhem RB, Udayanga D, Vaghefi N, Walther G, Wilk M, Wrzosek M, Xu JC, Yan JY, Zhou N (2014) One stop shop: backbones trees for important phytopathogenic genera: I. Fungal Divers 67:21–125

Hyde KD, Hongsanan S, Jeewon R, Bhat DJ, McKenzie EHC, Jones EBG, Phookamsak R, Ariyawansa HA, Boonmee S, Zhao Q, Abdel-Aziz FA, Abdel-Wahab MA, Banmai S, Chomnunti P, Cui BK, Daranagama DA, Das K, Dayarathne MC, de Silva NI, Dissanayake AJ, Doilom M, Ekanayaka AH, Gibertoni TB, Góes-Neto A, Huang SK, Jayasiri SC, Jayawardena RS, Konta S, Lee HB, Li WJ, Lin CG, Liu JK, Lu YZ, Luo ZL, Manawasinghe IS, Manimohan P, Mapook A, Niskanen T, Norphanphoun C, Papizadeh M, Perera RH, Phukhamsakda C, Richter C, de Santiago ALCMA, Drechsler-Santos ER, Senanayake IC, Tanaka K, Tennakoon TMDS, Thambugala KM, Tian Q, Tibpromma S, Thongbai B, Vizzini A, Wanasinghe DN, Wijayawardene NN, Wu HX, Yang J, Zeng XY, Zhang H, Zhang JF, Bulgakov TS, Camporesi E, Bahkali AH, Amoozegar AM, Araujo-Neta LS, Ammirati JF, Baghela A, Bhatt RP, Bojantchev S, Buyck B, da Silva GA, de Lima CLF, de Oliveira RJV, de Souza CAF, Dai YC, Dima B, Duong TT, Ercole E, Mafalda-Freire F, Ghosh A, Hashimoto A, Kamolhan S, Kang JC, Karunarathna SC, Kirk PM, Kytovuori I, Lantieri A, Liimatainen K, Liu ZY, Liu XZ, Lucking R, Medardi G, Mortimer PE, Nguyen TTT, Promputtha I, Raj KNA, Reck MA, Lumyong S, Shahzadeh-Fazeli SA, Stadler M, Soudi MR, Su HY, Takahashi T, Tangthirasunun N, Uniyal P, Wang Y, Wen TC, Xu JC, Zhang ZK, Zhao YC, Zhou JZ, Zhu L (2016) Fungal diversity notes 367–490: taxonomic and phylogenetic contributions to fungal taxa. Fungal Divers 80:1–270

Hyde KD, Norphanphoun C, Abreu VP, Bazzicalupo A, Chethana KWT, Clericuzio M, Dayarathne MC, Dissanayake AJ, Ekanayaka AH, He MQ, Hongsanan S, Huang SK, Jayasiri SC, Jayawardena RS, Karunarathna A, Konta S, Kusan I, Lee H, Li J, Lin CG, Liu NG, Lu YZ, Luo ZL, Manawasinghe IS, Mapook A, Perera RH, Phookamsak R, Phukhamsakda C, Siedlecki I, Soares AM, Tennakoon DS, Tian Q, Tibpromma S, Wanasinghe DN, Xiao YP, Yang J, Zeng XY, Abdel-Aziz FA, Li WJ, Senanayake IC, Shang QJ, Daranagama DA, de Silva NI, Thambugala KM, Abdel-Wahab MA, Bahkali AH, Berbee ML, Boonmee S, Bhat DJ, Bulgakov TS, Buyck B, Camporesi E, Castaneda-Ruiz RF, Chomnunti P, Doilom M, Dovana F, Gibertoni TB, Jadan M, Jeewon R, Jones EBG, Kang JC, Karunarathna SC, Lim YW, Liu JK, Liu ZY, Plautz HL Jr, Lumyong S, Maharachchikumbura SSN, Matocec N, McKenzie EHC, Mesic A, Miller D, Pawłowska J, Pereira OL, Promputtha I, Romero AL, Ryvarden L, Su HY, Suetrong S, Tkalcec Z, Vizzini A, Wen TC, Wisitrassameewong K, Wrzosek M, Xu JC, Zhao Q, Zhao RL, Mortimer PE (2017) Fungal diversity notes 603–708: taxonomic and phylogenetic notes on genera and species. Fungal Divers 87:1–235

Hyde KD, Chaiwan N, Norphanphoun C, Boonmee S, Camporesi E, Chethana KWT, Dayarathne MC, de Silva NI, Dissanayake AJ, Ekanayaka AH, Hongsanan S, Huang SK, Jayasiri SC, Jayawardena RS, Jiang HB, Karunarathna A, Lin CG, Liu JK, Liu NG, Lu YZ, Luo ZL, Maharachchimbura SSN, Manawasinghe IS, Pem D, Perera RH, Phukhamsakda C, Samarakoon MC, Senwanna C, Shang QJ, Tennakoon DS, Thambugala KM, Tibpromma S, Wanasinghe DN, Xiao YP, Yang J, Zeng XY, Zhang JF, Zhang SN, Bulgakov TS, Bhat DJ, Cheewangkoon R, Goh TK, Jones EBG, Kang JC, Jeewon R, Liu ZY, Lumyong S, Kuo CH, McKenzie EHC, Wen TC, Yan JY, Zhao Q (2018) Mycosphere notes 169–224. Mycosphere 9:271–430

Jayawardena RS, Hyde KD, Jeewon R, Liu XH, Liu M, Yan JY (2016a) Why it is important to correctly name *Colletotrichum* species? Mycosphere 7:1076–1092

Jayawardena RS, Hyde KD, Damm U, Cai L, Liu M, Li XH, Zhang W, Zhao WS, Yan JY (2016b) Notes on currently accepted species of *Colletotrichum*. Mycosphere 7:1192–1260

Karunarathna SC, Guinberteau J, Chen J, Vellinga EC, Zhao RL, Chukeatirote E, Yan J, Hyde KD, Callac P (2014) Two new species in *Agaricus* tropical clade I. Chiang Mai J Sci 41:771–780

Karunarathna SC, Chen J, Mortimer P, Xu JC, Zhao RL, Callac P, Hyde KD (2016) Mycosphere Essay 8: a review of genus *Agaricus* in tropical and humid subtropical regions of Asia. Mycosphere 7:417–439

Kaur M, Kaur H, Malik NA (2016) Identification and characterization of six new taxa of genus *Agaricus* L.:FR. (Agaricaceae Chevall.) from India. World J Pharm Pharm Sci 5:1518–1533

Kerrigan RW (2016) *Agaricus* of North America. Botanical Garden, New York

Koukol O, Delgado G, Hofmann TA, Piepenbring M (2018) Panama, a hot spot for *Hermatomyces* (Hermatomycetaceae, Pleosporales) with five new species, and a critical synopsis of the genus. IMA Fungus 9:107–141

Kruys Å, Huhndorf SM, Miller AM (2015) Coprophilous contributions to the phylogeny of Lasiosphaeriaceae and allied taxa within Sordariales (Ascomycota, Fungi). Fungal Divers 70:101–113

Kuhnert E, Surup F, Sir EB, Lambert C, Hyde KD, Hladki AI, Romero AI, Stadler M (2015) Lenormandins A-G, new azaphilones from *Hypoxylon lenormandii* and *Hypoxylon jaklitschii* sp. nov., recognised by chemotaxonomic data. Fungal Divers 71:165–184

Le TH (2007) Biodiversity of the fungi genus *Lactarius* (Basidiomycota) in Northern Thailand. PhD dissertation, Chiang Mai University

Li SF, Xi YL, Qi CX, Liang QQ, Wei SL, Li GJ, Zhao D, Lia SJ, Wenb HA (2014) *Agaricus taeniatus* sp. nov., a new member of *Agaricus* sect. Bivelares from northwest China. Mycotaxon 129:187–196

Li GJ, Hyde KD, Zhao RL, Hongsanan S, Abdel-Aziz FA, Abdel-Wahab MA, Alvarado P, Alves-Silva G, Ammirati JF, Ariyawansa HA, Baghela A, Bahkali AH, Beug M, Bhat DJ, Bojantchev D, Boonpratuang T, Bulgakov TS, Camporesi E, Boro MC, Ceska O, Chakraborty D, Chen JJ, Chethana KWT, Chomnunti P, Consiglio G, Cui BK, Dai DQ, Dai YC, Daranagama DA, Das K, Dayarathne MC, De Crop E, De Oliveira RJV, de Souza CAF, de Souza JI, Dentinger BTM, Dissanayake AJ, Doilom M, Drechsler-Santos ER, Ghobad-Nejhad M, Gilmore SP, Góes-Neto A, Gorczak M, Haitjema CH, Hapuarachchi KK, Hashimoto A, He MQ, Henske JK, Hirayama K, Iribarren MJ, Jayasiri SC, Jayawardena RS, Jeon SJ, Jerônimo GH, Jesus AL, Jones EBG, Kang JC, Karunarathna SC, Kirk PM, Konta S, Kuhnert E, Langer E, Lee HS, Lee HB, Li WJ, Li XH, Liimatainen K, Lima DX, Lin CG, Liu JK, Liu XZ, Liu ZY, Luangsa-ard JJ, Lücking R, Lumbsch HT, Lumyong S, Leaño EM, Marano AV, Matsumura M, McKenzie EHC, Mongkolsamrit S, Mortimer PE, Nguyen TTT, Niskanen T, Norphanphoun C, O'Malley MA, Parnmen S, Pawłowska J, Perera RH, Phookamsak R, Phukhamsakda C, Pires-Zottarelli CLA, Raspé O, Reck MA, Rocha SCO, de Santiago ALCMA, Senanayake IC, Setti L, Shang QJ, Singh SK, Sir EB, Solomon KV, Song J, Srikitikulchai P, Stadler M, Suetrong S, Takahashi H, Takahashi T, Tanaka K, Tang LP, Thambugala KM, Thanakitpipattana D, Theodorou MK, Thongbai B, Thummarukcharoen T, Tian Q, Tibpromma S, Verbeken A, Vizzini A, Vlasák J, Voigt K, Wanasinghe DN, Wang Y, Weerakoon G, Wen HA, Wen TC, Wijayawardene NN, Wongkanoun S, Wrzosek M, Xiao YP, Xu JC, Yan JY, Yang J, Da Yang S, Hu Y, Zhang JF, Zhao J, Zhou LW, Peršoh D, Phillips AJL, Maharachchikumbura SSN (2016) Fungal Diversity notes 253–366: taxonomic and phylogenetic contributions to fungal taxa. Fungal Divers 78:1–237

Liu F, Cai L, Crous PW, Damm U (2014) The *Colletotrichum gigasporum* species complex. Persoonia 33:83–97

Liu JK, Hyde KD, Jones EBG, Ariyawansa HA, Bhat DJ, Boonmee S, Maharachchikumbura S, McKenzie EHC, Phookamsak R, Phukhamsakda C, Shenoy BD, Abdel-Wahab MA, Buyck B, Chen J, Chethana KWT, Singtripop C, Dai DQ, Dai YC, Daranagama DA, Dissanayake AJ, Doliom M, D'souza MJ, Fan XL, Goonasekara ID, Hirayama K, Hongsanan S, Jayasiri SC, Jayawardena RS, Karunarathna SC, Li WJ, Mapook A, Norphanphoun C, Pang KL, Perera RH, Persoh D, Pinruan U, Senanayake IC, Somrithipol S, Suetrong S, Tanaka K, Thambugala KM, Tian Q, Tibpromma S, Udayanga D, Wijayawardena NN, Wanasinghe D, Wisitrassameewong K, Abdel-Aziz FA, Adamck S, Bahkali AH, Boonyuen N, Bulgakov T, Callac P, Chomnunti P, Greiner K, Hashimoto A, Hofstetter V, Kang JC, Lewis D, Li XH, Liu XX, Liu ZY, Matumura M, Mortimer PE, Rambold G, Randrianjohany E, Sato G, Sri-Indrasutdhi V, Tian CM, Verbeken A, von Brackel W, Wang Y, Wen TC, Xu JC, Yan JY, Zhao RL, Camporesi E (2015) Fungal diversity notes 1–110: taxonomic and phylogenetic contributions to fungal species. Fungal Divers 72:1–197

Lorsuwan C, Tontyaporn S, Visarathanonth N, Manoch L, Kakishima M (1984) Materials for the rust flora in Thailand I. Trans Mycol Soc Jpn 25:57–65

Ma X, Nontachaiyapoom, Jayawardena RS, Hyde KD, Gentekaki E, Zhou S, Qian Y, Wen T, Kang J (2018) Endophytic *Colletotrichum* species from *Dendrobium* spp. in China and Northern Thailand. MycoKeys 42

Maharachchikumbura SSN, Hyde KD, Jones EBG, McKenzie EHC, Bhat DJ, Dayarathne MC, Huang SK, Norphanphoun C, Senanayake IC, Perera RH, Shang QJ, Xiao YP, Dsouza MJ, Hongsanan S, Jayawardena RS, Daranagama DA, Konta S, Goonasekara ID, Zhuang WY, Jeewon R, Phillips AJL, AbdelWahab MA, Al-Sadi AM, Bahkali AH, Boonmee S, Boonyuen N, Cheewangkoon R, Dissanayake AJ, Kang JC, Li QR, Liu JK, Liu XZ, Liu ZY, Luangsa-ard JJ, Pang KL, Phookamsak R, Promputtha I, Suetrong S, Stadler M, Wen TC, Wijayawardene NN (2016) Families of Sordariomycetes. Fungal Divers 79:1–317

Mahdizadeh V, Alberto Parra L, Safaie N, Mohammadi EG, Chen J, Guinberteau J, Callac P (2018) A phylogenetic and morphological overview of sections *Bohusia*, *Sanguinolenti*, and allied sections within *Agaricus* subg. *Pseudochitonia* with three new species from France, Iran and Portugal. Fungal Biol 112:34–53

Manamgoda DS, Udayanga D, Cai L, Chukeatirote E, Hyde KD (2013) Endophytic *Colletotrichum* from tropical grasses with a new species *C. endophytica*. Fungal Divers 61:107–115

Manoch L, Tokumasu S, Tubaki K (1986) A preliminary survey of microfungal flora of pine leaf litter in Thailand. Trans Mycol Soc Jpn 27:159–165

Mapook A, Hyde KD, Dai DQ, Li J, Jones EG, Bahkali AH, Boonmee S (2016) Muyocopronales, ord. nov., (Dothideomycetes, Ascomycota) and a reappraisal of *Muyocopron* species from northern Thailand. Phytotaxa 265:225–237

Masel AM, Irwin JAG, Manners JM (1993) Mini-chromosomes of *Colletotrichum* spp. infecting several host species in various countries. Mycol Res 97:852–856

Meeboon J, Takamatsu S (2017) New records of *Erysiphe* sect. *Uncinula* spp. (Erysiphales) from Thailand and *E. liquidambaris* var. *acalycinae* var. nov. Mycoscience 58:236–241

Meeboon J, Hidayat I, To-anun C (2007) An annotated list of cercosporoid fungi in northern Thailand. J Agric Technol 3:51–63

Mekkamol S (1998) Endophytic fungi of *Tectona grandis* l. (teak). PhD Thesis, Liverpool John Moores University, England

Murrell ZE (1993) Phylogenetic relationships in *Cornus* (Cornaceae). Syst Bot 1:469–495

Noireung P, Phoulivong S, Liu F, Cai L, Mckenzie EH, Chukeatirote E, Jones EBG, Bahkali AH, Hyde KD (2012) Novel species of *Colletotrichum* revealed by morphology and molecular analysis. Cryptogam, Mycol 33:347–362

Norphanphoun C, Raspé O, Jeewon R, Wen TC, Hyde KD (2018) Morphological and phylogenetic characterisation of novel *Cytospora* species associated with mangroves. MycoKeys 38:93–120

Noshiro S, Baas P (1998) Systematic wood anatomy of Cornaceae and allies. IAWA J 19:43–97

Oeurn S, Jitjak W, Sanoamuang N (2015) Fungi on dragon fruit in Loei Province, Thailand and the ability of *Bipolaris cactivora* to cause post-harvest fruit rot. KKU Res J 20:405–418

Okane I, Toyama K, Nakagiri A, Suzuki KI, Srikitikulchai P, Sivichai S, Hywel-Jones N, Potacharoen W, Læssøe T (2008) Study of endophytic Xylariaceae in Thailand: diversity and taxonomy inferred from rDNA sequence analyses with saprobes forming fruit bodies in the field. Mycoscience 49:359–372

Ou S (1980) A look at worldwide rice blast disease control. Plant Dis 64:439–445

Parra LA (2008) *Agaricus* L. Allopsalliota, Nauta & Bas. Fungi Europaei 1. Edizioni Candusso, Alassio, Italy

Parra LA, Angelini C, Ortiz-Santana B, Mata G, Billette C, Rojo C, Chen J, Callac P (2018) The genus *Agaricus* in the Caribbean. Nine new taxa mostly based on collections from the Dominican Republic. Phytotaxa 345:219–271

Paul SS, Bu DP, Xu JC, Hyde KD, Yu ZT (2018) A phylogenetic census of global diversity of gut anaerobic fungi and a new taxonomic framework. Fungal Divers 89:253–266

Perera RH, Hyde KD, Dissanayake AJ, Jones EB, Liu JK, Wei D, Liu ZY (2018) Diaporthe collariana sp. nov., with prominent collarettes associated with *Magnolia champaca* fruits in Thailand. Stud Fungi 3:141–151

Petrak F (1921) Mykologische Notizen. II. Ann Mycol 19(1–2):17–128

Petrak F (1925) Mykologische Notizen. VIII. Ann Mycol 23(1–2):1–143

Phookamsak R, Norphanphoun C, Tanaka K, Dai DQ, Luo ZL, Liu JK, Su HY, Bhat DJ, Bahkali AH, Mortimer PE, Xu JC (2015) Towards a natural classification of *Astrosphaeriella*-like species; introducing Astrosphaeriellaceae and Pseudoastrosphaeriellaceae fam. nov. and *Astrosphaeriellopsis*, gen. nov. Fungal Divers 74:143–197

Photita W, Taylor PWJ, Rebecca F, Hyde KD, Lumyong S (2004) Morphological and molecular characterization of *Colletotrichum* species from herbaceous plants in Thailand. Fungal Divers 18:117–133

Phoulivong S, Cai L, Chen H, McKenzie EH, Abdelsalam K, Chukeatirote E, Hyde KD (2010) *Colletotrichum gloeosporioides* is not a common pathogen on tropical fruits. Fungal Divers 44:33–43

Pinnoi A, Pinuran U, Hyde KD, McKenzie EHC, Lumyong S (2004) *Submersisphaeria palmae* sp. nov. with a key to species, and notes on *Helicoubisia*. Sydowia 56:72–78

Pinnoi A, Lumyong S, Hyde KD, Jones EBG (2006) Biodiversity of fungi on the palm *Eleiodoxa conferta* in Sirindhorn peat swamp forest, Narathiwat, Thailand. Fungal Divers 22:205–218

Pinnoi A, Phongpaichit P, Jeewon R, Tang AMC, Hyde KD, Jones EBG (2010) Phylogenetic relationships of *Astrocystis eleiodoxae* sp. nov. (Xylariaceae). Mycosphere 1:1–9

Pinruan U, Hyde KD, Lumyong S, McKenzie EHC, Jones EBG (2007) Occurrence of fungi on tissues of the peat swamp palm *Licuala longicalycata*. Fungal Divers 25:157–173

Pointing SB, Hyde KD (2001) Bio-expoitation of filamentus fungi. Fungal Divers Res Ser 6:1–467

Pointing SB, Pelling AL, Smith GJD, Hyde KD, Reddy CA (2005) Screening of basidiomycetes and xylariaceous fungi for lignin peroxidase and laccase gene-specific sequences. Mycol Res 109:115–124

Prihastuti H, Cai L, Chen H, McKenzie EHC, Hyde KD (2009) Characterization of *Colletotrichum* species associated with coffee berries in northern Thailand. Fungal Divers 39:89–109

Promputtha I, Lumyong S, Lumyong P, McKenzie EHC, Hyde KD (2004) Fungal saprobes on dead leaves of *Magnolia liliifera* (Magnoliaceae) in Thailand. Cryptogram Mycol 25:315–321

Rehner SA, Uecker FA (1994) Nuclear ribosomal internal transcribed spacer phylogeny and host diversity in the coelomycete *Phomopsis*. Can J Bot 72:1666–1674

Richter C, Helaly SE, Thongbai B, Hyde KD, Stadler M (2016) Pyristriatins A and B—pyridino-cyathane antibiotics from the basidiomycete *Cyathus* cf. *striatus*. J Nat Prod 79:1684–1688

Rovná K, Bakay L, Petrová J, Terentjeva M, Černá J, Kačániová M (2015) Characterization of endophytic microflora of *Rosa canina* fruits. J Microbiol Biotechnol Food Sci 4:65–68

Saccardo PA (1898) Sylloge fungorum omnium hucusque cognitorun, vol XIII. In: Sydow AP (ed) Index universalis et locupletissimus hospitum fungorum. Roy. 8 vol, part I. Fratres Borntraeger, Berolini, pp 1–624

Salgado-Salazar C, Cepero MC, Realpe E, Restrepo S (2008) Histological analyses of the fungal endophytes in *Rosa hybrida*. Rev Iberoam Micol 24:323–324

Samarakoon MC, Peršoh D, Hyde KD, Bulgakov TS, Manawasinghe IS, Jayawardena RS (2018) *Colletotrichum acidae* sp. nov. from northern Thailand and a new record of *C. dematium* on *Iris* sp. Mycosphere 9:583–597

Sandargo B, Thongbai B, Stadler M, Surup F (2018) Cysteine-derived pleurotin congeners from the nematode-trapping basidiomycete *Hohenbuehelia grisea*. J Nat Prod 81:286–291

Sangpueak R, Phansak P, Buensanteai N (2018) Morphological and molecular identification of *Colletotrichum* species with cassava anthracnose in Thailand. J Phytopathol 166:129–142

Sanmee R, Tulloss RE, Lumyong P, Dell B, Lumyong S (2008) Studies on *Amanita* (Basidiomycetes: Amanitaceae) in Northern Thailand. Fungal Divers 32:97–123

Santos JM, Phillips AJL (2009) Resolving the complex of *Diaporthe* (*Phomopsis*) species occurring on *Foeniculum vulgare* in Portugal. Fungal Divers 34:111–125

Santos JM, Vrandecic K, Cosic J, Duvnjak T, Phillips AJL (2011) Resolving the *Diaporthe* species occurring on soybean in Croatia. Persoonia 27:9–19

Santos L, Phillips AJL, Crous PW, Alves A (2017) *Diaporthe* species on Rosaceae with descriptions of *D. pyracanthae* sp. nov. and *D. malorum* sp. nov. Mycosphere 8:485–511

Schoch CL, Crous PW, Groenewald JZ, Boehm EWA, Burgess TI, De Gruyter J, De Hoog GS, Dixon LJ, Grube M, Gueidan C, Harada Y (2009) A class-wide phylogenetic assessment of Dothideomycetes. Stud Mycol 64:1–15

Senanayake IC, Maharachchikumbura SSN, Hyde KD, Bhat JD, Jones EBG, McKenzie EHC, Dai DQ, Daranagama DA, Dayarathne MC, Goonasekara ID, Konta S, Li WJ, Shang QJ, Stadler M, Wijayawardene NN, Xiao YP, Norphanphoun C, Li Q, Liu XZ, Bahkali AH, Kang JC, Wang Y, Wen TC, Wendt L, Xu JC, Camporesi E (2015) Towards unraveling relationships in Xylariomycetidae (Sordariomycetes). Fungal Divers 73:73–144

Shang QJ, Hyde KD, Phookamsak R, Doilom M, Bhat DJ, Maharachchikumbura SS, Promputtha I (2017) Diatrypella tectonae and Peroneutypa mackenziei spp. nov. (Diatrypaceae) from northern Thailand. Mycol Prog 16:463–476

Shenoy BD, Jeewon R, Lam WH, Hyde KD, Bhat DJ, Taylor PWJ (2007) Morpho-molecular characterisation and epitypification of *Colletotrichum capsici*, causal agent of anthracnose in chilli. Fungal Divers 27:197–211

Sherriff C, Whelan MJ, Arnold GM, Bailey JA (1995) rDNA sequence analysis confirms the distinction between *Colletotrichum graminicola* and *C. sublineolum*. Mycol Res 99:475–478

Singtripop C, Hongsanan S, Li JF, De Silva NI, Phillips AJL, Jones EBG, Bahkali AH, Hyde KD (2016) *Chaetothyrina mangiferae* sp. nov., a new species of *Chaetothyrina*. Phytotaxa 255:021–033

Sivanesan A (1987) *Graminicolous* species of *Bipolaris*, *Curvularia, Drechslera, Exserohilum* and their teleomorphs. Myc Papers 158:1–261

Sivichai S, Goh TK, Hyde KD, Hywel-Jones NL (1998) The genus *Brachydesmiella* from submerged wood in the tropics, including a new species and a new combination. Mycoscience 39:239–247

Sontirat P, Pitakpaivan P, Khamhangridthirong T, Choobamroong W, Kueprakone U (1994) Host index of plant diseases in Thailand, 3rd edn. Mycology section. Plant Pathology and Microbiology Division, Department of Agriculture, Bangkok

Su YY, Noireung P, Liu F, Hyde KD, Moslem MA, Bahkali AH, Abd-Elsalam KA, Cai L (2011) Epitypification of *Colletotrichum musae*, the causative agent of banana anthracnose. Mycoscience 52:376–382

Sung GH, Sung JM, Hywel-Jones NL, Spatafora JW (2007) A multigene phylogeny of Clavicipitaceae (Ascomycota, Fungi): identification of localized incongruence using a combinational bootstrap approach. Mol Phylogenet Evol 44:1204–1223

Surup F, Thongbai B, Kuhnert E, Hyde KD, Stadler M (2015) Deconins A-E—unprecedented cuparenic and mevalonic or propionic acid conjugates from the basidomycete *Deconica* sp. 471. J Nat Prod 78:934–938

Suwannarat S, Steinkellner S, Songkumarn P, Sangchote S (2017) Diversity of *Colletotrichum* spp. isolated from chili pepper fruit exhibiting symptoms of anthracnose in Thailand. Mycol Prog 16(7):677–686

Tang AMC, Jeewon R, Hyde KD (2005) Successional patterns of microfungi in fallen leaves of *Castanopsis fissa* (Fagaceae) in Hong Kong forest. Can J Microbiol 51:967–974

Tedersoo L, Bahram M, Põlme S, Kõljalg U, Yorou NS, Wijesundera R, Villarreal Ruiz L, Vasco-Palacios AM, Thu PQ, Suija A, Smith ME, Sharp C, Saluveer E, Saitta A, Rosas M, Riit T, Ratkowsky D, Pritsch K, Põldmaa K, Piepenbring M, Phosri C, Peterson M, Parts K, Pärtel K, Otsing E, Nouhra E, Njouonkou AL, Nilsson RH, Morgado LN, Mayor J, May TW, Majuakim L, Lodge DJ, Lee SS, Larsson KH, Kohout P, Hosaka K, Hiiesalu I, Henkel TW, Harend H, Guo LD, Greslebin A, Grelet G, Geml J, Gates G, Dunstan W, Dunk C, Drenkhan R, Dearnaley J, De Kesel A, Dang T, Chen X, Buegger F, Brearley FQ, Bonito G, Anslan S, Abell S, Abarenkov K (2014) Global diversity and geography of soil fungi. Science 346(6213):1256688

Tedersoo L, Bahram M, Puusepp R, Nilsson RH, James TY (2017) Novel soil-inhabiting clades fill gaps in the fungal tree of life. Microbiome 5(1):42

Tedersoo L, Sánchez-Ramírez S, Kõljalg U, Bahram M, Döring M, Schigel D, May T, Ryberg M, Abarenkov K (2018) High-level classification of the Fungi and a tool for evolutionary ecological analyses. Fungal Divers 90:135–159

Than PP, Jeewon R, Hyde KD, Pongsupasamit S, Mongkolporn O, Taylor PWJ (2008a) Characterization and pathogenicity of *Colletotrichum* species associated with anthracnose disease on chilli (*Capsicum* spp.) in Thailand. Plant Pathol 57:562–572

Than PP, Shivas RG, Jeewon R, Pongsupasamit S, Marney TS, Taylor PWJ, Hyde KD (2008b) Epitypification and phylogeny of *Colletotrichum acutatum* JH Simmonds. Fungal Divers 28:97–108

Thawthong A, Karunarathna SC, Thongklang N, Chukeatirote E, Kakumyan P, Chamyuang S, Rizal LM, Mortimer PE, Xu J, Callac P, Hyde KD (2014) Discovering and domesticating wild tropical cultivatable mushrooms. Chiang Mai J Sci 41:731–764

Thienhirun S (1997) A preliminary account of the Xylariaceae of Thailand. PhD Thesis, Liverpool John Moores University, Liverpool

Thongbai B, Surup F, Mohr K, Kuhnert E, Hyde KD, Stadler M (2013) Gymnopalynes A and B—Chloropropynyl-isocoumarin antibiotics from cultures of the basidiomycete *Gymnopus* sp. J Nat Prod 76:2141–2144

Thongbai B, Tulloss RE, Miller SL, Hyde KD, Chen J, Zhao R, Raspe O (2016) A new species and four new records of *Amanita* (Amanitaceae; Basidiomycota) from northern Thailand. Phytotaxa 286:211–231

Thongbai B, Miller SL, Stadler M, Wittstein K, Hyde KD, Lumyong S, Raspé O (2017a) Study of three interesting species of *Amanita* from Thailand based on multiple gene phylogeny and toxin analysis. PLoS ONE 12(8):e0182131

Thongbai B, Wittstein K, Richter C, Miller SL, Hyde KD, Thongklang N, Klomklung N, Chukeatirote E, Stadler M (2017b) Successful cultivation of a valuable wild strain of *Lepista sordida* from Thailand. Mycol Prog 16:211–223

Thongbai B, Hyde KD, Lumyong S, Raspé O (2018) High undescribed diversity of *Amanita* section *Vaginatae* in northern Thailand. Mycosphere 9(3):462–494

Thongkantha S, Lumyong S, McKenzie EHC, Hyde KD (2008) Fungal saprobes and pathogens occurring on tissues of *Dracaena lourieri* and *Pandanus* spp. in Thailand. Fungal Divers 30:149–169

Thongklang N, Nawaz R, Khalid AN, Chen J, Hyde KD, Zhao R, Parra LA, Hanif M, Moinard M, Callac P (2014) Morphological and molecular characterization of three *Agaricus* species from tropical Asia (Pakistan, Thailand) reveals a new group in section *Xanthodermatei*. Mycologia 106:1220–1232

Thongklang N, Chen J, Bandara AR, Hyde KD, Raspé O, Parra LA, Callac P (2016) Studies on *Agaricus subtilipes*, a new cultivatable species from Thailand, incidentally reveal the presence of *Agaricus subrufescens* in Africa. Mycoscience 4:239–250

Thongklang N, Thongbai B, Chamyuang S, Callac P, Chukeatirote E, Hyde KD, Wittstein K, Stadler M (2017) Blazeispirol A, a chemotaxonomic marker from mycelia of the medicinal mushroom *Agaricus subrufescens*. Chiang Mai J Sci 44:298–308

Tian Q, Doilom M, Luo ZL, Chomnunti P, Bhat JD, Xu JC, Hyde KD (2016) Introducing *Melanoctonatectonae* gen. et sp. nov. and *Minimelanolocus yunnanensis* sp. nov. (Herpotrichiellaceae, Chaetothyriales). Cryptogam, Mycol 37:477–492

Tibpromma S, Boonmee S, Wijayawardene NN, Maharachchikumbura SS, McKenzie EH, Bahkali AH, Gareth JE, Hyde KD, Promputtha I (2016a) The holomorph of *Parasarcopodium* (Stachybotryaceae), introducing *P. pandanicola* sp. nov. on *Pandanus* sp. Phytotaxa 266:250–260

Tibpromma S, Bhat J, Doilom M, Lumyong S, Nontachaiyapoom S, Yang JB, Hyde KD (2016b) Three new *Hermatomyces* species (Lophiotremataceae) on *Pandanus odorifer* from Southern Thailand. Phytotaxa 275:127–139

Tibpromma S, Daranagama DA, Boonmee S, Promputtha I, Nontachaiyapoom S, Hyde KD (2017a) *Anthostomelloides krabiensis* gen. et sp. nov. (Xylariaceae) from *Pandanus odorifer* (Pandanaceae). Turk J Bot 41:107–116

Tibpromma S, Hyde KD, Jeewon R, Maharachchikumbura SSN, Liu JK, Bhat DJ, McKenzie EHC, Jones EBG, Camporesi E, Bulgakov TS, Doilom M, de Azevedo Santiago ALCM, Das K, Manimohan P, Gibertoni TB, Lim YW, Ekanayaka AH, Thongbai B, Lee HB, Yang JB, Kirk PM, Sysouphanthong P, Singh SK, Boonmee S, Dong W, Raj KNA, Latha KPD, Phookamsak R, Phukhamsakda C, Tennakoon DS, Li J, Dayarathne MJ, Perera RH, Xiao Y, Wanasinghe DN, Senanayake IC, Goonasekara ID, de Silva NI, Mapook A, Jayawardena RS, Dissanayake AJ, Manawasinghe IS, Chethana KWT, Luo ZL, Hapuarachchi KK, Baghela A, Soares AM, Vizzini A, Meiras-Ottoni A, Mesic A, Dutta AK, de Souza CAF, Richter C, Lin CG, Chakrabarty D, Daranagama DA, Lima DX, Chakraborty D, Ercole E, Wu F, Simonini G, Vasquez G, da Silva GA, Plautz HLP Jr, Ariyawansa HA, Lee H, Kusan I, Song J, Sun J, Karmakar J, Hu K, Semwal KC, Thambugala KM, Voigt K, Acharya K, Rajeshkumar KC, Ryvarden L, Jadan M, Hosen MI, Mikšýk M, Samarakoon MC, Wijayawardene NN, Kim NK, Matocec N, Singh PN, Tian Q, Bhatt RP, Jose R, de Oliveira V, Tulloss RE, Aamir S, Kaewchai S, Marathe SD, Khan S, Hongsanan S, Adhikari S, Mehmood T, Bandyopadhyay TK, Nguyen TTT, Antonýn V, Li WJ, Wang Y, Indoliya Y, Tkalcec Z, Elgorban AM, Bahkali AH, Tang AMC, Su HY, Zhang H, Promputtha I, Luangsaard J, Xu J, Yan J, Kang JC, Stadler M, Mortimer PT, Chomnunti P, Zhao Q, Phillips AJL, Nontachaiyapoom S, Wen TC, Karunarathna SC (2017b) Fungal diversity notes 491–602: taxonomic and phylogenetic contributions to fungal taxa. Fungal Divers 83:1–261

Tibpromma S, Hyde KD, Bhat JD, Mortimer PE, Xu J, Promputtha I, Doilom M, Yang JB, Tang AM, Karunarathna SC (2018a) Identification of endophytic fungi from leaves of Pandanaceae based on their morphotypes and DNA sequence data from southern Thailand. MycoKeys 33:25–67

Tibpromma S, Hyde KD, McKenzie EHC, Bhat DJ, Phillips Alan JL, Wanasinghe DN, Samarakoon MC, Jayawardena RS, Dissanayake AJ, Tennakoon DS, Doilom M, Phookamsak R, Tang AMC, Xu J, Mortimer PE, Promputtha I, Maharachchikumbura SSN, Khan S, Karunarathna SC (2018b) Fungal diversity notes 840–928: micro-fungi associated with Pandanaceae. Fungal Divers 92:1–160

To-anun C, Hidayat I, Meeboon J (2011) Genus *Cercospora* in Thailand: taxonomy and Phylogeny (with a dichotomous key to species). Plant Pathol Quar 1:11–87

Tokumasu S, Tubaki K, Manoch L (1990) A preliminary list of hyphomycetes isolated from pine leaf litter of Thailand. Rep Tottori Mycol Inst 28:185–190

Tongsri V, Songkumarn P, Sangchote S (2016) Leaf spot characteristics of *Phomopsis durionis* on durian (Durio Zibethinus Murray) and latent infection of the pathogen. Acta Univ Agric Silvic Mendel Brun 64:185–193

Tulloss RE, Yang ZL (2018) Studies in the Amanitaceae. http://www.amanitaceae.org/. Accessed 31 Aug 2018

Udayanga D, Liu X, McKenzie EH, Chukeatirote E, Bahkali AH, Hyde KD (2011) The genus *Phomopsis*, biology, applications, species concepts and names of common pathogens. Fungal Divers 50:189–225

Udayanga D, Liu XZ, Crous PW, McKenzie EHC, Chukeatirote E, Hyde KD (2012a) A multi-locus phylogenetic evaluation of *Diaporthe* (*Phomopsis*). Fungal Divers 56:157–171

Udayanga D, Liu XZ, McKenzie EHC, Chukeatirote E, Hyde KD (2012b) Multi-locus phylogeny reveals three new species of *Diaporthe* from Thailand. Crypt Mycol 33:295–309

Udayanga D, Manamgoda DS, Liu XZ, Chukeatirote E, Hyde KD (2013) What are the common anthracnose pathogens of tropical fruits? Fungal Divers 61:165–179

Udayanga D, Castlebury LA, Rossman AY, Chukeatirote E, Hyde KD (2014) Insights into the genus *Diaporthe*, phylogenetic species delimitation in the *D. eres* species complex. Fungal Divers 67:203–229

Verbeken A, Stubbe D, Van de Putte K, Eberhardt U, Nuytinck J (2014) Tales of the unexpected: antiocarpous representatives of the Russulaceae in tropical South East Asia. Persoonia 32:13–24

Wanasinghe DN, Phookamsak R, Jeewon R, Li WJ, Hyde KD, Jones EBG, Camporesi E, Promputtha I (2017) A family level rDNA based phylogeny of Cucurbitariaceae and Fenestellaceae with descriptions of new *Fenestella* species and *Neocucurbitaria* gen. nov. Mycosphere 8:397–414

Wanasinghe DN, Phukhamsakda C, Hyde KD, Jeewon R, Lee HB, Jones EBG, Tibpromma S, Tennakoon DS, Dissanayake AJ, Jayasiri SC, Gafforov Y, Camporesi E, Bulgakov TS, Ekanayake AH, Perera RH, Samarakoon MC, Goonasekara ID, Mapook A, Li WJ, Indunil C, Senanayake IC, Li JF, Norphanphoun C, Doilom M, Bahkali AH, Xu JC, Mortimer PE, Tibell L, Tibell S, Karunarathna SC (2018) Fungal diversity notes 709–839: taxonomic and phylogenetic contributions to fungal taxa with an emphasis on fungi on Rosaceae. Fungal Divers 89:1–236

Wang ZR, Parra LA, Callac P, Zhou JL, Fu WJ, Dui SH, Hyde KD, Zhao RL (2015) Edible species of *Agaricus* (Agaricaceae) from Xinjiang Province (Western China). Phytotaxa 202:185–197

Wang N, Lu BH, Yang LN, Wang X, Yang C, Liu LP, Zhang YJ, Gao J, Wang N (2017) *Fusarium avenaceum* causing fruit rot on *Rubus idaeus* in Jilin Province, China. Plant Dis 101:1037

Watkinson S, Boddy L, Money N (2015) The fungi, 3rd edn. Academic Press, London

Weiß M, Yang ZL, Oberwinkler F (1998) Molecular phylogenetic studies in the genus *Amanita*. Can J Bot 76:1170–1179

Whitton SR, McKenzie EH, Hyde KD (2012) Fungi associated with Pandanaceae. Springer, Dordrecht

Wijayawardene NN, Goonasekara ID, Camporesi E, Wang Y, An YL (2016) Two new *Seimatosporium* species from Italy. Mycosphere 7:204–213

Wikee S, Lombard L, Crous PW, Nakashima C, Motohashi K, Chukeatirote E, Alias SA, McKenzie EH, Hyde KD (2013a) *Phyllosticta capitalensis*, a widespread endophyte of plants. Fungal Divers 60:91–105

Wikee S, Lombard L, Nakashima C, Motohashi K, Chukeatirote E, Cheewangkoon R, McKenzie EHC, Hyde KD, Crous PW (2013b) A phylogenetic re–evaluation of *Phyllosticta* (Botryosphaeriales). Stud Mycol 76:1–29

Wisitrassameewong K, Karunarathna SC, Thongklang N, Zhao R, Callac P, Moukha S, Ferandon C, Chukeatirote E, Hyde KD (2012a) *Agaricus subrufescens*: a review. Saudi J Biol Sci 19:131–146

Wisitrassameewong K, Karunarathna SC, Thongklang N, Zhao RL, Callac P, Chukeatirote E, Bahkali AH, Hyde KD (2012b) *Agaricus subrufescens*: new records to Thailand. Chiang Mai J Sci 39:281–291

Wisitrassameewong K, Nuytinck J, Hyde KD, Verbeken A (2014a) *Lactarius* subgenus *Russularia* (Russulaceae) in Southeast Asia: 1. Species with very distant gills. Phytotaxa 158:023–042

Wisitrassameewong K, Nuytinck J, Hampe F, Hyde KD, Verbeken A (2014b) *Lactarius* subgenus *Russularia* (Russulaceae) in Southeast Asia: 2. Species with remarkably small basidiocarps. Phytotaxa 188:181–197

Wisitrassameewong K, Nuytinck J, Le Thanh H, De Crop E, Hampe F, Hyde KD, Verbeken A (2015) *Lactarius* subgenus *Russularia* (Russulaceae) in Southeast Asia: 3. New diversity in Thailand and Vietnam. Phytotaxa 207:215–241

Wolfe BE, Tulloss RE, Pringle A (2012) The irreversible loss of a decomposition pathway marks the single origin of an ectomycorrhizal symbiosis. PLoS ONE 7:e39597

Wu HX, Schoch CL, Boonmee S, Bahkali AH, Chomnunti P, Hyde KD (2011) A reappraisal of Microthyriaceae. Fungal Divers 51:189–248

Wurzbacher C, Nilsson RH, Rautio M, Peura S (2017) Poorly known microbial taxa dominate the microbiome of permafrost thaw ponds. ISME J 11:1938–1941

Xiang QY, Thomas DT, Zhang W, Manchester SR, Murrell Z (2006) Species level phylogeny of the genus *Cornus* (Cornaceae) based on molecular and morphological evidence—implications for taxonomy and Tertiary intercontinental migration. Taxon 55:9–30

Xiao YP, Wen TC, Hongsanan S, Sun JZ, Hyde KD (2017) Introducing *Ophiocordyceps thanathonensis*, a new species of entomogenous fungi on ants, and a reference specimen for *O. pseudolloydii*. Phytotaxa 328:115

Xiao YP, Wen TC, Hongsanan S, Jeewon R, Luangsa-ard JJ, Brooks S, Nadeeshan D, Long FY, Hyde KD (2018) Multigene phylogenetics of Polycephalomyces (Ophiocordycipitaceae, Hypocreales), with two new species from Thailand. Sci Rep (accepted)

Yan YC, Zhang ZX, Song YJ, Deng DF, Liu ZY (2015) First report of *Prunus serrulata* stem canker caused by *Botryosphaeria dothidea* in China. Plant Dis 100:858

Yang ZL (1997) Die Amanita-Arten von Südwestchina. Bibl Mycol 170:1–240

Yang YL, Liu ZY, Cai L, Hyde KD, Yu ZN, McKenzie EHC (2009) *Colletotrichum anthracnose* of Amaryllidaceae. Fungal Divers 39:123–146

Zadoks JC (1985) On the conceptual basis of crop loss assessment: the threshold theory. Annu Rev Phytopathol 23:455–473

Zeng XY, Wen TC, Chomnunti P, Liu JK, Boonmee S, Hyde KD (2016) *Ceramothyrium longivolcaniforme* sp. nov., a new species of Chaetothyriaceae from northern Thailand. Phytotaxa 267:51–60

Zeng XY, Jeewon R, Wen TC, Hongsanan S, Boonmee S, Hyde KD (2018a) Simplified and efficient DNA extraction protocol for Meliolaceae specimens. Mycol Prog 17:403–415

Zeng XY, Hongsanan S, Hyde KD, Putarak C, Wen TC (2018b) *Translucidithyrium thailandicum* gen. et sp. nov.: a new genus in Phaeothecoidiellaceae. Mycol Prog 17:1087–1096

Zhang LF, Yang JB, Yang ZL (2004) Molecular phylogeny of eastern Asian species of *Amanita* (Agaricales, Basidiomycota): taxonomic and biogeographic implications. Fungal Divers 17:219–238

Zhang SN, Hyde KD, Jones EG, Cheewangkoon R, Boonmee S, Doilom M, Mapook A, Liu JK (2017a) *Novomicrothelia pandanicola* sp. nov., a non-lichenized, Trypetheliaceae species from *Pandanus*. Phytotaxa 321:254–264

Zhang MZ, Li GJ, Dai RC, Xi YL, Wei SL, Zhao RL (2017b) The edible wide mushrooms of *Agaricus* section *Bivelares* from Western China. Mycosphere 8:1640–1652

Zhao RL (2008) Systematics of *Agaricus*, *Cyathus* and *Micropsalliota* in Northern Thailand. PhD Thesis, KMITL, Bangkok, Thailand

Zhao R, Karunarathna S, Raspé O, Parra LA, Guinberteau J, Moinard M, De Kesel A, Barroso G, Courtecuisse R, Hyde KD, Guelly AK (2011) Major clades in tropical *Agaricus*. Fungal Divers 51:279–296

Zhao RL, Desjardin DE, Callac P, Parra LA, Guinberteau J, Soytong K, Karunarathna S, Zhang Y, Hyde KD (2012a) Two species of *Agaricus* sect. *Xanthodermatei* from Thailand. Mycotaxon 122:187–195

Zhao RL, Hyde KD, Karunarathna SC, Desjardin DE, Raspé O, Soytong K, Guinberteau J, Callac P (2012b) *Agaricus floccu-losipes* sp. nov., a new potentially cultivatable species from the palaeotropics. Mycoscience 53:300–311

Zhao RL, Zhou JL, Chen J, Margaritescu S, Sánchez-Ramírez S, Hyde KD, Callac P, Parra LA, Li GJ, Moncalvo JM (2016) Towards standardizing taxonomic ranks using divergence times—a case study for reconstruction of the *Agaricus* taxonomic system. Fungal Divers 78:239–292

Zhou JL, Su SY, Su HY, Wang B, Callac P, Guinberteau J, Hyde KD, Zhao RL (2016) A description of eleven new species of *Agaricus* sections *Xanthodermatei* and *Hondenses* collected from Tibet and the surrounding areas. Phytotaxa 257:99–121

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