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https://gmsmicrofungi.org: an online database providing updated information of microfungi in the Greater Mekong Subregion

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Abstract

The Greater Mekong Subregion is a biodiversity hotspot including Yunnan Province, China and Thailand. It is home to an extremely large diversity of microfungi. The highly variable climate and vast range of floral diversity facilitates rapid speciation and diversity in microfungi. During the last few decades, microfungi from the Greater Mekong Subregion on different substrates have been published and reclassified, and many new species have been introduced. However, numerous knowledge gaps concerning species diversity and systematics, challenge the current understanding of the fungi in the region. Basic information of microfungi in the Greater Mekong Subregion, such as taxonomic diversity, molecular phylogeny and host-specificity is incomplete, and available data have not been integrated on a specific platform where all data can be easily retrieved. To address this issue, a website: https://gmsmicrofungi.org, focusing on the microfungi reported from the Greater Mekong Subregion has been developed. This website is a portal to comprehensive information on microfungi and updated notes of species reported from the Greater Mekong Subregion, with easily accessible and searchable functions.

Key words – Ascomycota – Chinese mycota – fungi website – taxonomy – Thai mycota

Introduction

Microfungi play crucial roles and are important to natural ecosystems as decomposers that degrade dead organic materials. They are endophytic, pathogenic or saprobic, or they are can be epiphytes and symbionts depending on the environment (Hyde et al. 2014). Microfungi are also key

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organisms in the nutrient cycling process, which drives sustainable ecosystems (Vandenkoornhuyse et al. 2002, Zhang et al. 2017). They are diverse and ubiquitous heterotrophic organisms (Joshi & Chettri 2019). Mycorrhizal fungi share symbiotic relationships with plants by inhabiting plant roots (Kehri et al. 2018). They are vital for the productivity of farmland by supplying essential nutrients for plant growth (Chen et al. 2018). Saprobic microfungi penetrate substrates and enzymes are released that break down components (Bucher et al. 2004). Owing to the production of various secondary metabolites, microfungi are extremely important to human health and welfare (Jayakumar et al. 2016, Hyde et al. 2019). For example, *Penicillium* spp. are used to produce beta-lactam antibiotics, which are used in penicillin's and cephalosporins (Ozcengiz & Demain 2013). Microfungi are also important in biotechnological applications (Hyde et al. 2019).

In plant pathology, fungal species are responsible for significant economic losses and negative outcomes in agriculture, forestry and natural ecosystems (Jayawardena et al. 2020). Studies of systematics, biology and control of phytopathogenic fungi have not fully clarified lifestyles of pathogenic fungi (Hyde et al. 2014). The diversity of pathogenic fungi leads to a widespread species identification problem. As a part of natural ecosystems, they also play an important role in environments and remain poorly understood.

The current estimated species number of fungi is between 2.2 to 3.8 million (Hawksworth & Lücking 2017). It is important to establish fungal-host specificity and investigate fungal diversity in poorly studied countries or regions (Chethana et al. 2020a, Hyde et al. 2020a).

The Greater Mekong Subregion is a landscape influenced by the Mekong River, comprising Cambodia, the People's Republic of China (PRC, specifically Yunnan Province and Guangxi Zhuang Autonomous Region), Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand and Vietnam (Asian Development Bank 2012). The Greater Mekong Subregion is a biodiversity hotspot spanning temperate to tropical regions (Li et al. 2018, Estoque et al. 2019) and is home to the world's tropical and evergreen forests forming unique ecosystems with high levels of biodiversity (Smith et al. 2002). Moist and dry mixed deciduous forests have different tree communities at the upper and lower elevations. These forests contain valuable timber: teak (*Tectona grandis*) as well as the largest mangrove area around the Mekong River estuaries. Forests have been converted to crop plantations in southern Yunnan (China). The establishment of plantations for the production of rubber, coffee, tea, cashew nuts, cacao, coconut, sugarcane, para rubber and palm oil are the primary drivers of forest loss (Stibig et al. 2010, Senwanna et al. 2019, 2020, 2021).

The Greater Mekong Subregion microfungal diversity has been relatively well-studied in Yunnan Province, China and in northern Thailand, whereas other regions lack accurate and comprehensive documentation of fungal diversity. Yunnan Province is geographically circumscribed by the Tibet Autonomous Region to the northwest, Sichuan to the north, Guizhou to the east and the Zhuang Autonomous Region of Guangxi to the southeast. Yunnan shares an international border with Laos and Vietnam at the south and southeast periphery as well as with Myanmar at the west and southwest. Studies into Thailand's fungal diversity have been on the increase since 2015 (Ariyawansa et al. 2015, Liu et al. 2015, Chethana et al. 2020b, Hyde et al. 2020d). Only about 6,000 species descriptions have been reported from Yunnan Province in China of which around 3,000 species were higher fungi (Feng & Yang 2018), accounting for approximately 40% of all fungal taxa in China (Yang 2005). In northern Thailand, Hyde et al. (2018) reported that the percentage of new microfungi is up to 96%, showing a high diversity.

Many studies of microfungi have been carried out in the Greater Mekong Subregion , such as the diversity of terrestrial fungi on woody and leaf litter (Kodsueb et al. 2008, Boonmee et al. 2011, Promputtha et al. 2017), freshwater fungi on submerged wood (Luo et al. 2018a, b, Dong et al. 2020) and microfungi on various hosts – such as bamboo, *Chromolaena odorata*, *Clematis* spp., *Dracaena* spp., *Magnolia* spp., palms, *Pandanus* spp., *Rhododendron* spp. and *Tectona grandis* (teak) (Table 1). Karst fungi and cave fungi have also been studied in recent years (Zhang et al. 2020).

Table 1 Lists of microfungi published on various hosts and substrates in the Greater Mekong Subregion during the past decade.

Host	Location	References
Bamboo	Thailand, Yunnan (China)	Phookamsak et al. (2015), Dai et al. (2017)
Camellia spp.	Yunnan (China)	Abeywickrama et al. (2020)
Chromolaena odorata	Thailand	Mapook et al. (2020)
Clematis spp.	Thailand	Phukhamsakda et al. (2020)
Dead Woody Twigs	Yunnan (China)	Mortimer et al. (2021)
Decaying leaves	Vietnam	Yen et al. (2021)
Dracaena spp.	Thailand	Chaiwan et al. (2020a, b)
Eucalyptus plantations	Yunnan (China)	Li et al. (2020)
Insect fungi	Thailand	Xiao et al. (2019)
Leaves of plants with leaf spots or other lesions	Laos	Phengsintham et al. (2010a, b, 2013)
Magnolia spp.	Yunnan (China)	Wanasinghe et al. (2020)
Grasses	Thailand	Goonasekara et al. (2018), Hyde et al. (2018), Karunarathna et al. (2019, 2020), Brahmanage et al. (2020), Wanasinghe et al. (2020)
Musaceae	Thailand	Samarakoon et al. (2020)
Palms	Thailand	Wanasinghe et al. (2018a), Chen et al. (2020), Konta et al. (2020)
Pandanus spp.	Thailand, Yunnan (China)	Tibpromma et al. (2016, 2018)
Peanut kernels	Myanmar	Chein et al. (2019)
Rhizophora spp.	Thailand	Norphanphoun et al. (2019), Dayarathne et al. (2020)
Rhododendron spp.	Yunnan (China)	Tian et al. (2011), Li et al. (2016), Thiyagaraja et al. (2020)
Rosa spp.	Yunnan (China)	Wanasinghe et al. (2018b)
Submerged wood	Thailand, Yunnan (China)	Luo et al. (2019), Dong et al. (2020)
Tectona grandis (teak)	Thailand	Doilom et al. (2017)
Unidentified leaves	Myanmar	Nozawa et al. (2018)

However, basic information of microfungi, such as taxonomic diversity, molecular phylogeny, ecological roles, biogeographic distributions and host-specificity are either poorly understood or missing in other countries in this region, compared to Thailand and Yunnan, China. To address this issue, it is important to develop a database to collate all of the scattered information. An online platform of microfungi in the Greater Mekong Subregion will enrich our current knowledge and provide an up-to-date record.

Why we need an online database for microfungi in the Greater Mekong Subregion

The Greater Mekong Subregion is a region with a potentially high number of undiscovered fungal species. Studies continue to reveal novel taxa in the Greater Mekong Subregion at an remarkable pace (Tibpromma et al. 2016, 2018, Doilom et al. 2017, Hyde et al. 2018, 2020b, Phookamsak et al. 2019, Dong et al. 2020, Mapook et al. 2020, Phukhamsakda et al. 2020). In the case of microfungi, the numbers are likely to be even higher. This is because there are numerous cryptic species as well as undiscovered genera. The current taxonomic classification and systematics of microfungi in the Greater Mekong Subregion continue to lack up-to-date information, while many published data remain unintegrated. Therefore, it is important to collate all information in to a comprehensive, continuously updated database. The Greater Mekong Subregion website (gmsmicrofungi.org) has accordingly been configured to document all species of microfungi reported from this region. The database provides an updated list of microfungi in the Greater Mekong Subregion, specifically reporting relationships with host plants. The Greater Mekong Subregion website provides notes on each taxon reported from the Greater Mekong Subregion region, keeping abreast of current research. The Greater Mekong Subregion database, so

far, mainly incorporates microfungi reported from northern Thailand and Yunnan Province, China. The database will be further expanded to other parts of the Greater Mekong Subregion as new data becomes available. Data collection will provide a better understanding of microfungal ecology and distribution in different hosts and habitats in the Greater Mekong Subregion, and the website will serve as a directory for fungal biodiversity and host-specificity in the Greater Mekong Subregion.

What is on the website content?

The Greater Mekong Subregion website provides notes on each microfungus taxon reported from this region based on morphological and molecular data, keeping abreast of current research. Description and notes concerning placement and status are provided for each species. The entry represents published data of microfungi species reported from Greater Mekong Subregion, including species name, Faces of fungi number, Index Fungorum/MycoBank number, description, habitat, distribution, material examined, notes, photographic plates, culture, sequence availability and reference (Fig. 1).

We will further expand and include the synopses and keys to genera and species as well as other important data, wherever available through links from other related webpages including "Faces of Fungi" (Jayasiri et al. 2015; http://www.facesoffungi.org); "One Stop Shop" (Jayawardena et al. 2019) (https://onestopshopfungi.org); "Marine fungi" (Jones et al. 2019) (http://marinefungi.org); "Freshwater fungi" (Calabon et al. 2020) (http://freshwaterfungi.org); "Sordariomycetes" (Bundhun et al. 2020) (https://sordariomycetes.org); "Fungal Genera" (Monkai et al. 2020) (https://www.fungalgenera.org) and "Outline of Fungi" (Wijayawardene et al. 2020) (https://www.outlineoffungi.org).

Construction

All microfungi in the Greater Mekong Subregion area will be incorporated into the database according to the most recent classifications of Ascomycota (Wijayawardene et al. 2020). The database will be updated regularly as new information becomes available. Outlines, detailed descriptions and notes of each entry on the website will be carefully verified by the curators (Table 2).

Table 2 List of expert curators with their contact information.

Position	Name	Address	Contact information
Head Curators	Kevin D. Hyde	Center of Excellence in Fungal Research, School of Science Mae Fah Luang University, Chiang Rai, Thailand 57100	kdhyde3@gmail.com
	Peter E. Mortimer	Centre for Mountain Futures (CMF), Kunming Institute of Botany, Kunming 650201, Yunnan, People's Republic of China	petermortimer@mac.com
Managing curators	Dhanushka N. Wanasinghe	Centre for Mountain Futures (CMF), Kunming Institute of Botany, Kunming 650201, Yunnan, People's Republic of China	dnadeeshan@gmail.com
	Napalai Chaiwan	Center of Excellence in Fungal Research, School of Science, Mae Fah Luang University, Chiang Rai, Thailand 57100	baimai_napalai@hotmail.com
Curators	Jutamart Monkai	Center of Excellence in Fungal Research, School of Science, Mae Fah Luang University, Chiang Rai, Thailand 57100	mjutamart@gmail.com
	Rungtiwa Phookamsak	Centre for Mountain Futures (CMF), Kunming Institute of Botany, Kunming 650201, Yunnan, People's Republic of China	rphookamsak@outlook.com

Table 2 Continued.

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	Mingkwan Doilom	Innovative Institute for Plant Health, Zhongkai University of Agriculture and Engineering, Guangzhou 510225, Guangdong Province, People's Republic of China	j_hammochi@hotmail.com
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Database interface and visualization

The website gmsmicrofungi.org is an online platform that compiles published information based on the classification and taxonomy of microfungi in the Greater Mekong Subregion. The website's interface is simple and user-friendly (Fig. 1). The heading provides the nine features and functions of the website. The right side of the webpage lists all recent uploaded genera and species. The search toolbar can be found above 'Recent Genus' section of the webpage. To find the genus or taxon of interest, input relevant information in the search box and a pop-up window will suggest the target fungi, including its taxonomic level (Fig. 2). Clicking on the species name will direct you to the description, notes, photographic plates and phylogenetic tree of the microfungi in Greater Mekong Subregion (Fig. 3). The references used in the description and notes are linked to the original source to obtain information about the species

The nine different features and functions in the uppermost part as following:

1) Home page provides the ultimate goals of the webpage, the general information of the website (The menu of the functions including the search toolbar show Home, Host/substrate, Archives, Curators, History, References, News, Contact) and an overview of the Greater Mekong Subregion microfungi. Objectives of launching the website are also provided (Fig. 1) and also the reference of this webpage are show if user using the document of this website. The right side show the recent genus and recent species updated from the webpage.
2) Bottom view of the homepage (Fig. 2). This information shows contact details and supporting scholars.

3) The Host/Substrate tab when user click to this toolbar the function will provide the data about microfungi species. This tab lists all microfungi that have been reported from Greater Mekong Subregion by fungal classification range (Fig. 3).
4) The Archive tab is Greater Mekong Subregion microfungi with the outline of the orders and families of Greater Mekong Subregion microfungi (Fig. 4). When the user opens the "Archives", the list of orders related to Greater Mekong Subregion microfungi can be visualized. By clicking on a relevant order, the link will navigate to "Read more about the order" or related family list of the order. Inside families, the list of associated genera and species are available.
5) Search box (right side), searching species name such as *Phaeoacremonium italicum* and click "Go" to reveal the details about the species (Fig. 5). The information will show the name of microfungi, the Index Fungorum number and Facesoffungi number. The description with illustration of that microfungi, Culture characteristics, Habitat, known hosts or distribution, Material examined, GenBank Accession Number, Notes and reference of the data are also provided.
6) The Curators section provides the contact information and affiliated institutions of website curators (Fig. 6).
7) The History tab shows a short historical background of Greater Mekong Subregion microfungi, ascomycetes and host list of collection.
8) The References tab is a compilation of all published work (e.g., books, reviews, monographs and articles) and other information related to Greater Mekong Subregion microfungi are provided under this heading.
9) All activities and news related to mycology are shown in the news tab. Contact to the Home page. The 'Contact' section provides contact details for the website and allows users to address any comments and suggestions.

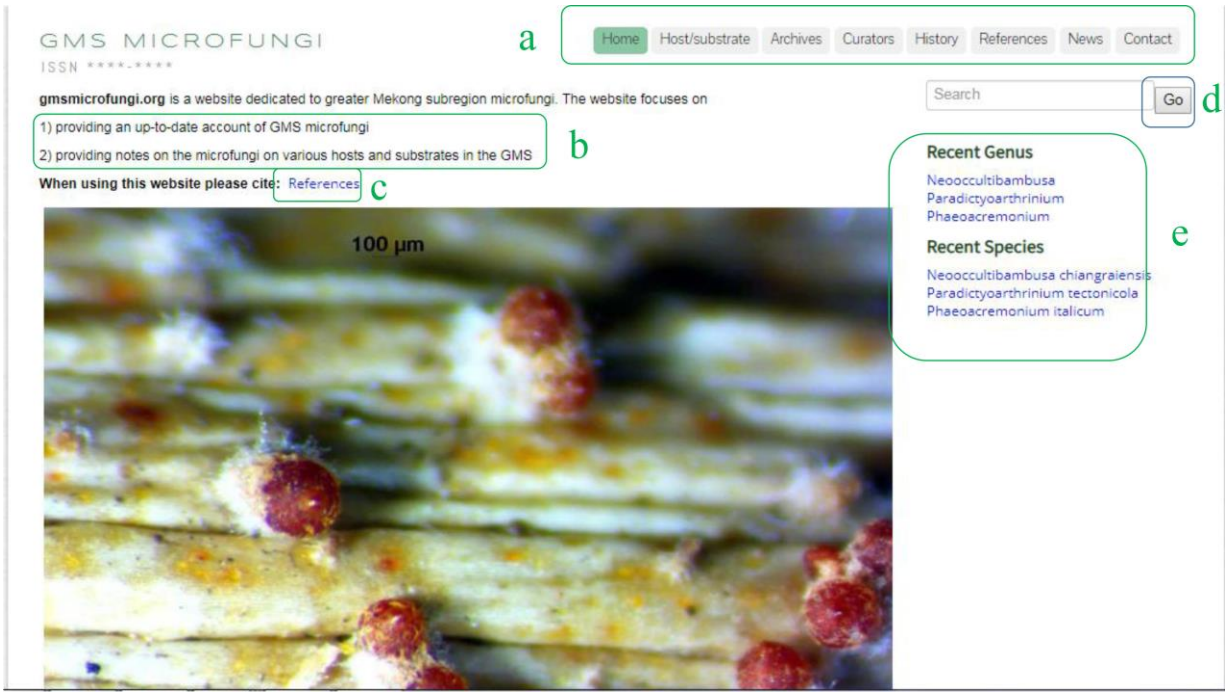

Figure 1 – The homepage view of Greater Mekong Subregion microfungi containing a photo slideshow, with Greater Mekong Subregion microfungi information, and different features and functions including the search toolbar and recent uploaded data. a Headers. b Objectives of the webpage. c Citation of the webpage. d Search box. e Recently updated news, recent genera and species.

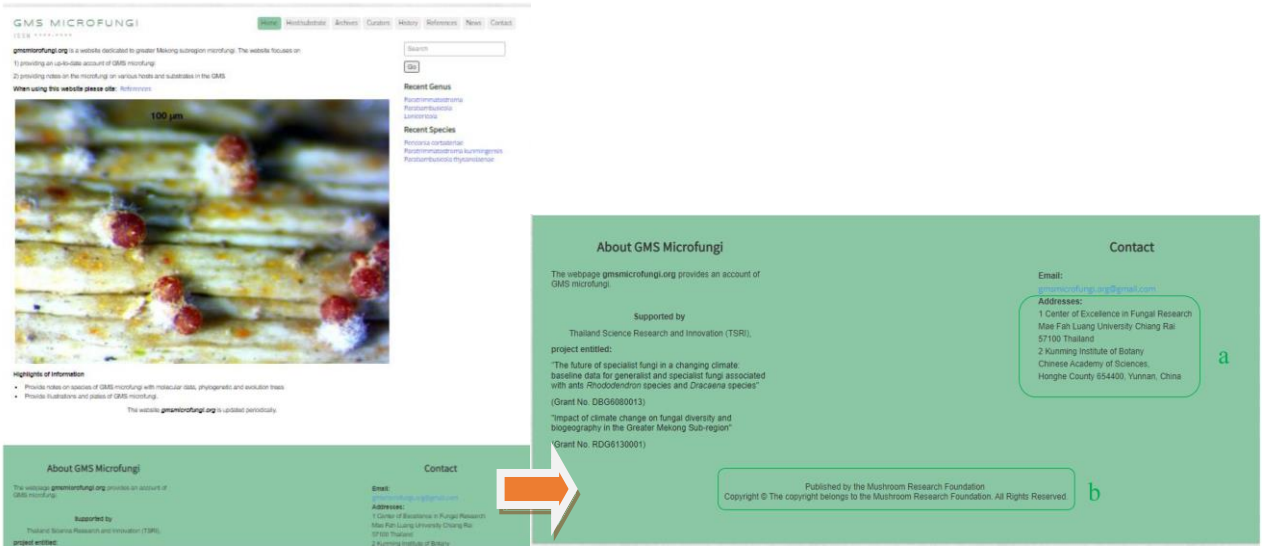

Figure 2 – Go to the bottom of the page. Bottom view of the homepage. a Contact details. b Publisher and copyright information.

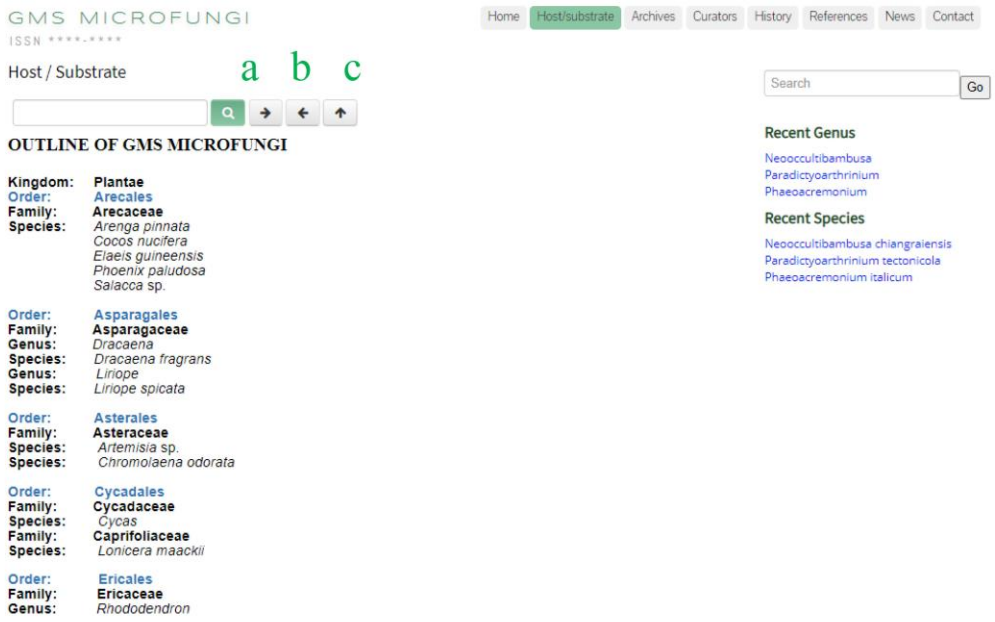

Figure 3 – The section host/substrate of the webpage. a Find next. b Find previous. c Back to top.

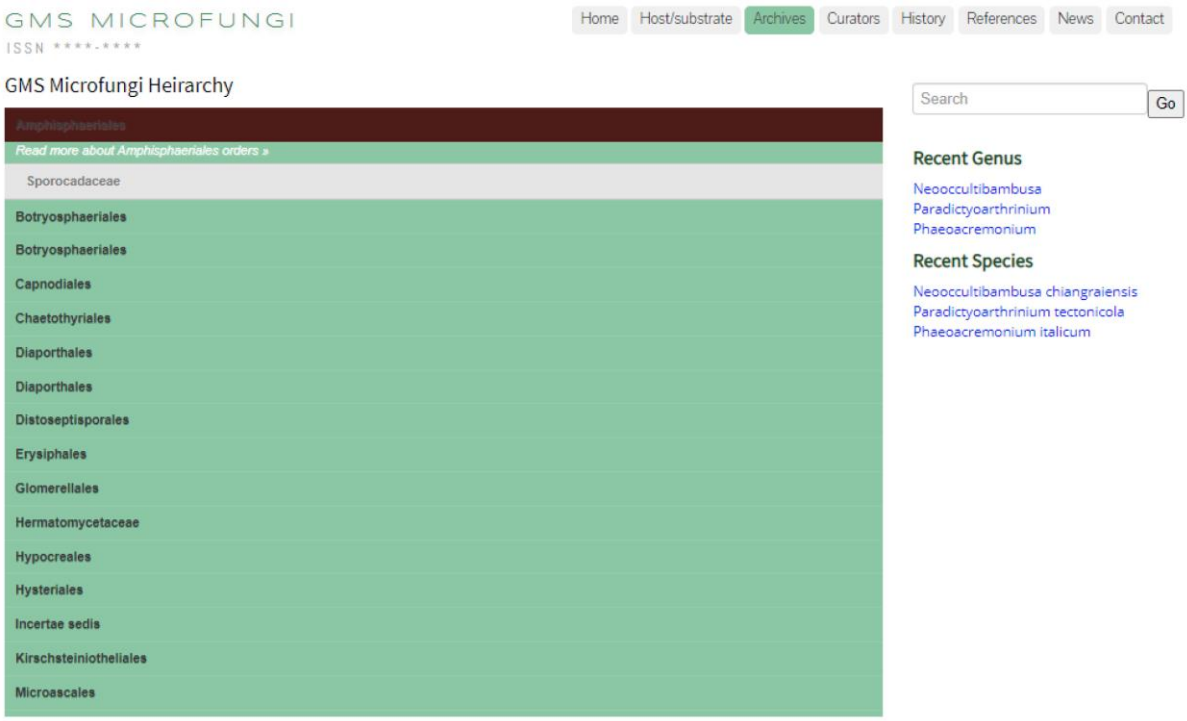

Figure 4 – The Archive tab with the outline of the orders and families of Greater Mekong Subregion microfungi.

Figure 5 – Clicking a species name such as *Phaeoacremonium italicum* reveals detailed description.

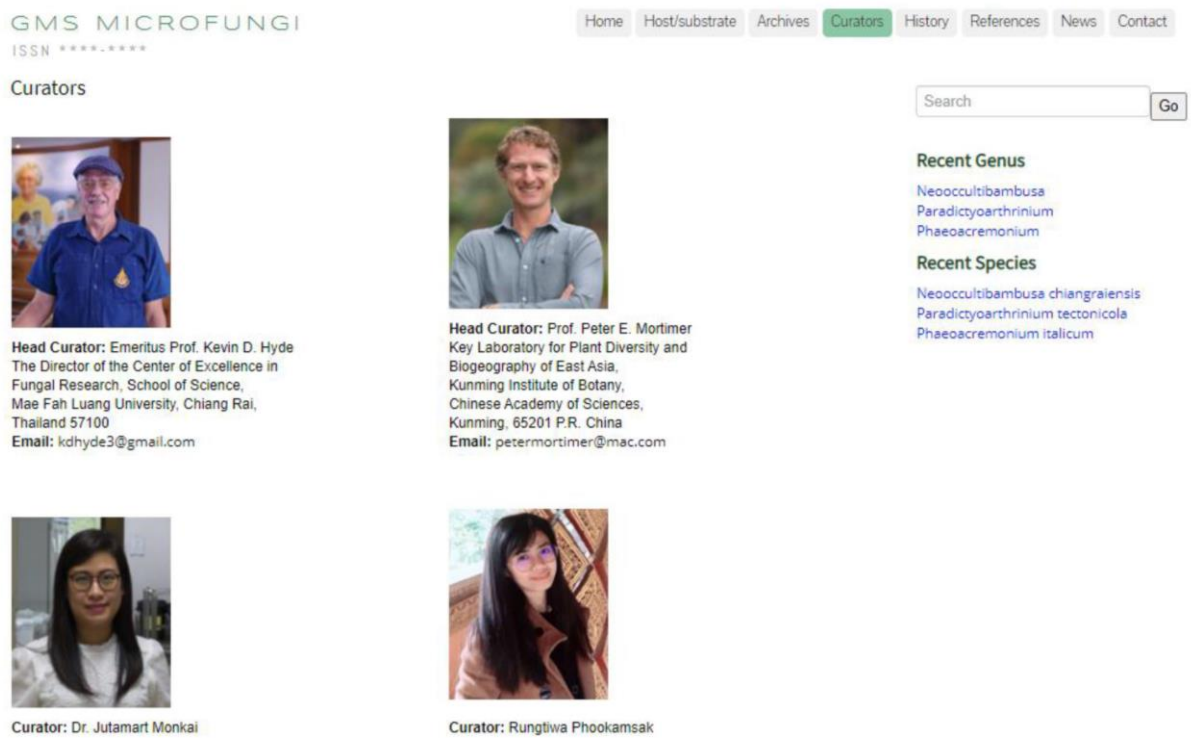

Figure 6 – Website curator information.

Discussion

Taxonomy links various databases that store information on different organisms. Several global fungal nomenclatural and taxonomic databases can be sourced to find the information about distribution of fungi. While knowledge on fungi and their hosts in tropical Southeast Asia is poor, this database will enrich our knowledge of fungi in Greater Mekong Subregion especially in Yunnan Province (China) and Thailand. The website provides basic information for mycologists to understand fungal distribution that can be exploited further.

The Greater Mekong Subregion is an ideal location to conduct diverse research on micro-fungal occurrences on specific areas/hosts. Yunnan Province of China and Thailand have tropical and subtropical climates that are favorable for fungal growth and reproduction. These areas are reported having a rich fungal diversity. More than 700 new fungal species have been described in Thailand (Hyde et al. 2018, 2020a, b, c). The idea of the webpage is to gather all this scattered published information in to one user-friendly platform.

The Greater Mekong Subregion microfungi website provides fungal classification information, host specific fungi and other related useful data in the Greater Mekong Subregion, which will enhance current understanding and ultimately enable mycologists to gain better and updated insights into the current fungal diversity in the Greater Mekong Subregion. In addition, the database also allows access to comprehensive data including descriptions of fungi, locations and specific plant-host information of fungi. This is a user-friendly database providing an up-to-date account of Greater Mekong Subregion microfungi and notes of microfungi on various hosts and substrates. The information includes Ascomycota and Eurotiomycetes (comprise four main classes Chaetothyriomycetidae, Dothideomycetes, Leotiomycetes and Sordariomycetes) in various hosts and substrates in the Greater Mekong Subregion. The webpage is managed by 12 experienced curators who upload and update information of fungi in the Greater Mekong Subregion. The present paper introduces the Greater Mekong Subregion microfungi database and provides classification and identification of the main fungal groups in the Greater Mekong Subregion. The presented data are reported from the Yunnan Province in China and Thailand.

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