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Living with giant ferns: An ethnobotanical investigation of scaly tree ferns (Cyatheaceae) in a global context

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ABSTRACT

Scaly tree ferns stand out among other pteridophytes not only due to their ancient lineage, which retains specific primitive characteristics in their appearance and growth habits, but also because of their remarkable diversity, local endemism, and distinctive ethnobotanical uses. Pteridophytes generally have received less attention than seed plants due to their limited economic potential and utility. Our experiences and knowledge show that scaly tree ferns possess substantial economic potential and offer higher utility than other fern groups. Analyzing ethnobotanical knowledge is a well-established technique and tool to understand any plant group's significance and economic potential. Therefore, we aimed to compile ethnobotanical knowledge related to scaly tree ferns from various ethnic groups worldwide, utilizing published information and consulting with key informants. In the present survey, 61 species of scaly tree ferns were identified that belong to four genera (*Alsophila, Cyathea, Gymnosphaera*, and *Sphaeropteris*), which are utilized across 41 countries worldwide. The ethnobotanical uses of these 61 tree fern species are classified into four user categories: medicinal, food and animal feed, ornamental, and other uses. This study underscores the potential for integrating traditional ethnobotanical knowledge about scaly tree ferns with modern scientific understanding. It also emphasizes the critical importance of preserving and compiling this knowledge that has been passed down through generations within traditional communities. This preservation ensures that such valuable knowledge is not lost to future generations.

1. Introduction

Ethnopteridology is a multidisciplinary field of study and a branch of ethnobotany that explores the relationship between humans and

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pteridophytes (Keller and Prance, 2015; Singh and Khare, 2011; Ranil and Bussmann, 2021). Despite their current minor ecological and economic significance compared to seed plants, they once dominated the world's vegetation and substantially contributed to the world's coal reserves (de Winter and Amoroso, 2003). Humans have recognized the therapeutic value of plant life as a crucial component of biological diversity since the dawn of civilization (Fiorin et al., 2019). Archaeological literature evidence that humans have been utilizing pteridophytes for over 2000 years, indicating a longstanding relationship between humans and them (Keller and Prance, 2015; Baskaran et al., 2018).

The field of Ethnopteridology extends beyond the traditional uses of pteridophytes, encompassing a wide range of knowledge on these plants, from their taxonomy and ecology to their pharmacology and conservation. Despite the remarkable diversity of pteridophytes in tropical regions, many countries, with the exceptions of China and India, are lagging in their efforts to explore and document traditional knowledge associated with pteridophytes (Ranil and Bussmann, 2021). Modern pteridological studies have made significant progress in elucidating the phylogenetic relationships and biogeographic affinities of these plants through advancements in molecular biology. Ethnopteridology should be given high priority in the field of pteridology because ethnopteridology is not merely a subject that deals solely with the traditional uses of pteridophytes but also serves as a reflective mirror of traditional communities' knowledge connected to various aspects of pteridophytes, including taxonomy, ecology, conservation, pharmacology, and more. Thus, we compiled ethnopteridological knowledge associated with various ethnic communities worldwide while developing a network among researchers interested in ethnobotany and pteridology. In this endeavor, we focused on scaly tree ferns, a group of species informally regarded as living fossils.

The extant scaly tree ferns (Cyatheaceae) are commonly distributed across tropical regions, from wet lowlands to mid-elevations (Bystriakova et al., 2011; Dong et al., 2022). They can be easily distinguished by the scales on their trunks and fronds. The Cyatheaceae family comprises approximately 643 species (PPG I, 2016). However, concern about these tree ferns is growing due to the alarming destruction of their natural habitat over the past five decades. This destruction is primarily driven by extensive human activities, including indiscriminate extraction, disturbances like forest fires, and the effects of climate change (Dadang et al., 2020; Pimm and Raven, 2000). Given their biological significance and the imminent threats they face, most of them have been included in Appendix II of the Convention on International Trade in Endangered Species (CITES), emphasizing the imperative for increased research efforts, conservation initiatives, and sustainable utilization practices.

Limited studies have unveiled the significance of ethnobotanical knowledge associated with scaly tree ferns, including their economic potential and user values. Despite the Neotropics and Southeast Asia being major centers of tree fern diversity, the relationship between people and tree ferns has not been adequately explored, as evidenced by the few studies conducted (Eleutério and Pérez-Salicrup, 2006; Suryana et al., 2018; Dadang et al., 2020). However, some studies conducted in India have provided impressive information on how traditional communities have utilized scaly tree ferns and their prospective economic significance (Kholia, 2012; Mishra and Behera, 2020). In addition to these works, numerous scattered studies and additional sources of information hold the potential to provide valuable insights into the understanding of the importance of exploring ethnobotanical knowledge. Hence, compiling information related to various applications of scaly tree ferns worldwide becomes imperative. Thus, our initiative was established as a collaborative network uniting researchers from regions of the greatest tree fern diversity. Through this network, our primary goal was to gather unique and vital knowledge on tree ferns dispersed within diverse ethnic communities worldwide.

2. Materials and methods

2.1. Investigative questions

1. How did traditional communities maintain their relationship with tree ferns?
2. What is the extent of traditional communities' knowledge regarding the utilization of tree ferns?
3. Can their traditional knowledge be integrated with modern practices and knowledge?
4. Do tree ferns possess a significant economic potential?

This study resulted from a collaborative effort among a consortium of researchers representing Africa, Asia, Europe, and South and Central America. Their expertise and field-based experiences in areas such as pteridology, ethnobotany, biodiversity conservation, and other related disciplines were utilized to enhance the current study. We employed a collective research approach to explore, document, analyze, and interpret ethnobotanical information related to tree ferns. The process commenced with authors networking and establishing the overall objective and initial framework of the proposed study. Subsequently, all authors uniformly adopted a consistent approach to collect, document, and analyze the information. This research gathered information by implementing three practical and efficient approaches. These approaches included 1) conducting an extensive literature survey referencing web-based data repositories, 2) consulting key informants, and 3) leveraging authors' experience and knowledge gained from engaging biological and ethnobotanical research.

2.2. Conducting an extensive literature survey

For the literature survey, the authors employed well-established scientific web-based platforms, including Web of Science, Google Scholar, and Research Gate, to retrieve pertinent information concerning traditional uses of tree ferns worldwide. The searches were conducted from August 2022 to September 2023, focusing on articles published in both English and the author's native languages. In addition, the authors also delved into web pages hosted on specific social media platforms devoted to Ferns and Lycophytes, Traditional Knowledge, and Biodiversity Conservation. While collecting information from web-based literature, we specifically focused on the following key aspects.

- Since there is a limited number of ethnopteridological studies on the web, initially, we searched for information on ethnobotanical surveys conducted mainly focusing on tropical and sub-tropical regions across the world.
- We conducted a thorough search for information on the various uses of tree ferns, utilizing keywords such as "ethnopteridology", "potential of ferns and lycophytes", "ethnobotany of pteridophytes", "economic potential of pteridophytes/ ferns", and "uses of ferns/ pteridophytes". The rationale behind this approach is that research is scarce on the traditional or modern uses of tree ferns.
- Since a substantial number of research studies have been conducted in the areas of ethnomedicine, ethnopharmacology, and the medicinal and phytochemical properties of pteridophytes, we conducted an extensive search for articles that could provide information related to their therapeutic values.
- We extensively utilized the terms "Tree ferns" and "Cyatheaceae" in our search for pertinent information, particularly emphasizing

geographical distribution patterns, floristic and ecological significance, and related aspects. However, we intentionally excluded substantial information related to molecular phylogeny and taxonomy from our scope of research.
- We explored information from websites, social media platforms, and other web-based data repositories, but we relied solely on information with authenticated references.

2.3. Consulting key informants

The authors consulted vital informants from the community, researchers, and administrators to gather additional information, validate their findings, and ensure the accuracy of facts drawn from the literature. The authors employed various methods to consult and gather information from key informants. These approaches included informal discussions over the phone and email, direct visits, and on-site visits to important locations such as nurseries, village fairs, markets, botanic gardens, and forest ecosystems.

2.4. Leveraging authors' experience and knowledge

All the authors engaged with this study have extensive experience in field-based botanical and ethnobotanical exploration, both within and beyond their regions. Their expertise and field-based experiences in areas such as botany, pteridology, ethnobotany, biodiversity conservation, and other related disciplines were utilized to enhance the current study. These valuable experiences, knowledge, and personal databases significantly contributed to shaping the present study and ultimately led to its excellent outcomes.

2.5. Data tabulation, analysis, and presentation

Finally, the gathered results information has been presented in this report using tables, maps, descriptive diagrams, and comprehensive discussions across five primary sections: (1) folk nomenclature, (2) uses as food and animal feed, (3) ethnomedicinal applications, (4) aesthetic and ornamental purposes, and (5) other utilitarian uses. The distribution map and data representation diagram were prepared using R statistical software (version 4.2.1). The PPG I (2016) classification system is generally followed, with the inclusion of more recent revisions for specific genera, as per the updated scientific names provided on the World Plant website (www.worldplants.de/ferns).

3. Results and discussion

3.1. Diversity and the distribution of tree fern species used by ethnic communities

The present survey identified 61 species of scaly tree ferns, which are utilized by ethnic communities in 41 countries from Asia (20 spp.), Africa (5 spp.), Central and South America (29 spp.), and the Pacific region (7 spp.) (Fig. 1). A total of 61 distinct species have been identified and categorized into four separate genera: *Alsophila, Cyathea, Gymnosphaera*, and *Sphaeropteris*, all of which belong to the family Cyatheaceae. The genus *Cyathea* stands out with the most significant number of species, boasting a total of 26, while *Alsophia, Sphaeropteris,* and *Gymnosphaera* consist of 23, 7, and 5 species, respectively. Hereinafter, the term "tree ferns" will specifically refer to the species within the family Cyatheaceae, also known as scaly tree ferns. When considering the distribution pattern of identified species, approximately 50% of the species were reported from the Neotropics, followed by Asia (33%). Although Southeast Asia is the center of tree fern diversity in Asia, the highest number of species with user value was recorded in South Asia.

Asia, in particular, is home to a substantial number of species attributed to food, medicinal, and ornamental uses of tree ferns. Although the African continent is an important center of diversity for tree ferns (Holttum, 1981; Roux, 2009), particularly Madagascar and neighboring islands (Janssen and Rakotondrainibe, 2008), our research revealed only a limited number of traditionally used species (e.g. *A. manniana, Alsophila dregei* and *Gymnosphaera capensis*)

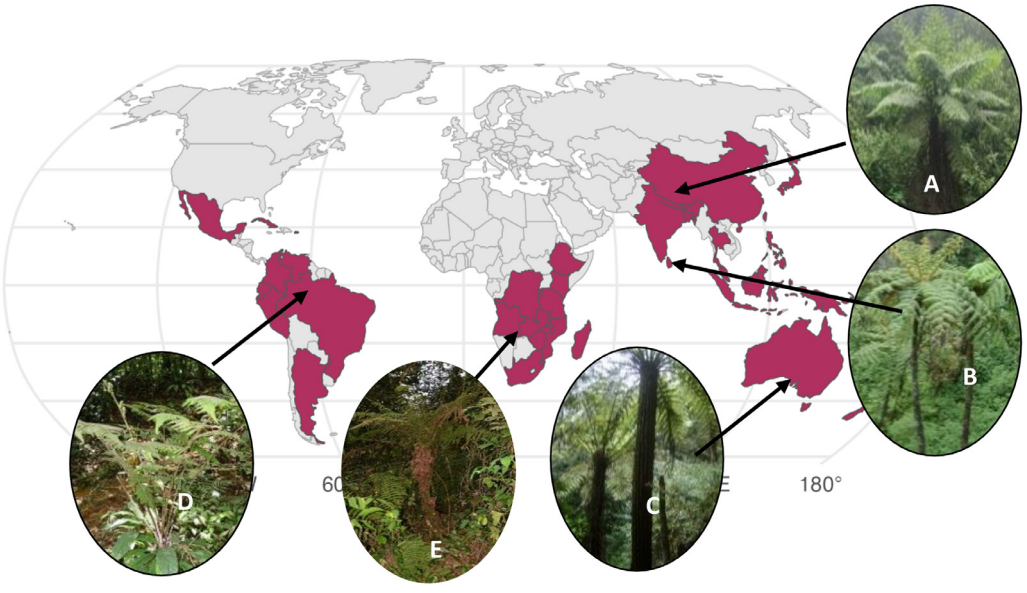

Fig.1. The map of the countries where information was collected for the review and a few species with traditional uses. A. *Alsophila spinulosa*, a widely utilized species in Nepal; B. *Alsophila crinita*, a species confined to Sri Lanka and South India which provides multiple benefits to the community; C. *Alsophila australis*, a species endemic to Australia which has been used by Aboriginals as human food and animal feed; D. *Cyathea surinamensis,* a species used as a medicinal plant in Brazil; E. *Alsophila camerooniana*, a species distributed from West Tropical Africa to Angola. Photographs by Rijan Ojha (A), Ranil Rajapaksha (B,C), Michael Hassler (D) and Ndolo Ebika & David Harris (E).

Note: The map includes 41 countries from Asia (Bangladesh, Bhutan, China, India, Indonesia, Japan, Malaysia, Nepal, the Philippines, Sri Lanka, Taiwan, Thailand, Vietnam), Africa (Angola, Burundi, Democratic Republic of the Congo, Ethiopia, Eswatini, Kenya, Madagascar, Malawi, Mozambique, Rwanda, South Africa, Tanzania, Zimbabwe, Zambia), Central and South America (Argentina, Brazil, Colombia, Cuba, Ecuador, Mexico, Peru, Venezuela), the Caribbean (Puerto Rico), and the Pacific region (Australia, New Zealand, Papua New Guinea, Solomon Islands, Vanuatu).

(Bouquet, 1969; Dlamini, 1981); Hutchings et al., 1996; Rwangabo, 1993). Since Africa is a significant center of tree fern diversity, making it essential to specifically focus on revealing the connection between tree ferns and indigenous communities across the continent. Notably, despite being vascular plants, most studies have traditionally categorized pteridophytes under seed plants when conducting community surveys. Thus, limited studies have been conducted directly focusing on the ethnobotany of pteridophytes or tree ferns in many countries.

3.2. Tree ferns as mirrors of traditional wisdom

In our study, we have successfully compiled and synthesized scattered information, revealing the solid scientific foundation of the link between ethnobotanical knowledge and tree ferns within traditional communities. These findings clearly demonstrate the untapped potential of tree ferns, revealing the extent of knowledge required to harness diverse benefits from these currently underutilized and neglected resources. Moreover, they emphasize the future economic prospects associated with tree ferns. Additionally, this research sheds light on the robust and harmonious relationship that exists between traditional communities, nature, and these remarkable ferns. From this point forward, we present compelling evidence to substantiate the exceptional traditional knowledge held by diverse ethnic groups in biologically rich regions and demonstrate its potential for integration into contemporary contexts. All the information presented here is categorized into two primary thematic areas: (a) folk nomenclature and (b) ethnobotanical uses of tree ferns.

3.3. Folk nomenclature

Folk nomenclature is a subset of ethnotaxonomy, reflecting the knowledge and understanding of traditional communities regarding the characteristics of plants and their unique relationship with the plant kingdom. The local names that indigenous people assign to plants in their native languages encompass a wealth of knowledge regarding their insights into these plants. These folk names provide insights into etymology, including therapeutic properties, mythical associations, and allegorical meanings, as well as specific characteristics and uses of particular species (Nnamani et al., 2019; Ranil and Bussmann, 2021). In Table 1, we have compiled the vernacular names used to designate “tree ferns” by various ethnic communities in selected countries. Sometimes, these names are specifically used for particular tree fern species or an entire group of tree ferns. When they are assigning names, they have specifically considered the most visible morphological features of a species.

For example, In Nepal, *A. spinulosa* is named “Chattre”, which means having an umbrella-shaped crown. In Brazil, tree ferns are known as “samambaiaçu” in the Tupi language, which translates to “big ferns”. Additionally, they are also referred to as “Coqueiro-macho”, meaning “male coconut tree”. This interesting name was given to them due to the absence of visible fruits on the tree at any given time (Fino Traço, 2016). *Alsophila manniana* is locally known as “Chusu” in the Kasigau Taita area of Kenya, which means “ferns” (Medley and Kalibo, 2007). While local names assigned to specific species are typically derived from specific morphological characteristics, there are instances where species are named plants based on other attributes such as organoleptic properties, therapeutic value, usage, or habitat characteristics. For example, tree ferns of Sri Lanka are generally known as “Gini-hota”, and Ranil et al. (2004) reported that some villagers around the forest reserves had used the upper part of the tree trunk as a light source after burning. When it burns, it resembles a bird’s beak, so villagers named it “Gini-hota” (“Gini” = fire; “hota” = the bird’s beak). In Vietnam, tree ferns are locally referred to as “Rang tien toa”, which means that they resemble a place for a fairy to sit down. While in Malaysia, particularly in Sabah, tree ferns are referred as “pakis gajah” or “paku gajah”, which means the fern (referring to pakis/paku in Malay) itself is as big as an elephant (gajah in Malay language). Sometimes, local indigenous people in Sabah also call tree ferns as “paku itom”, which refers to their blackish stipe (petiole) colors. This indicates that these names are associated with both the utility and the morphology of particular species. However, these vernacular names are known for their user-friendly, meaningful, and memorable qualities, and they are passed down from generation to generation with ease.

3.4. Ethnobotanical uses of tree ferns

From this point onward, we will discuss the facts related to the diverse ethnobotanical uses of tree ferns, which have been gathered from published journal articles, scientific reports, and firsthand

Table 1
Vernacular names used to designate “tree ferns” by various communities across the world.

Country	Local names	References
Indonesia	Pakis tihang, Pakis sieur, Bagedor, Pakis minyak, Pakis Payung, Pakis cempor, Pakis bulu, and Sijabrig	Suryana et al. (2018)
Malaysia	Pakis gajah, paku gajah, paku itom	Andi et al. (2010)
DRC	Oyaele, kishiembe	Yamada (1999); Termote et al. (2011)
Sri Lanka	Gini-hota, Gini-watara, Gini-dawata, Gini-wata	Ranil and Bussmann (2021)
Brazil	Samambaiaçu, Samambaia, Coqueiro-macho, Pau-cardoso, Fetos-arbóreos, Pau-cardoso, Rabo-de-bugio, Xaxim	Fino Traço (2016); de Medeiros et al. (2023)
Japan	Hego	Personal communication with Dr. Atsushi Ebihara, Japan
Bhutan	Nakay Shing	Dorji et al. (2022)
Vanuatu	Nesjau, Karsapang, Karsapang, Nithwunitei, Natemehas, Nithwunitei, Nimto, Noukwetao or Nukwetau, Nusjau or Nesjuaw, Nukwetuou	Ranker et al. (2022)
Nepal	Chattre, Rukh uniyu, Thulo uniyu	Kunwar (2017); Ojha and Devkota (2021)
New Zealand	Mamaku, Katātā, Kōrau, or Pītau.	Leach (2003)
West-papuwa	Ambin, Ilhik, Mui, Meme, Huphup, Pinde, Sambom, Waklia	Milliken (1992)
Bangladesh	Brun brikkha, Kontami brikkha, Baro brikkha, Henri brikkha, Kata brikkha	After consultation with tribal groups.
India	Lai-changkhrang	Yumkham and Singh (2011)
Philippines	Anonotong. Gantaw	Coritico (2014); Dadang et al. (2020)
Vietnam	Duong xi go, Rang tien toa	Pham (1999); Tran (2012);
Taiwan	Suoluo, Bitongshu, Shemu, Shujue	Shieh (1994)
Honduras	Carmirín, Mano de león, Petatillo	Cibrián and Sutherland (2007)
Colombia	Tasis	Jimenez-Ortega and Palacios-Mosquera (2019)
México	Guayaba de montaña, Helecho arborescente	Pérez-Paredes et al. (2014)
Cuba	Helecho arborescente	Regalado et al. (2015)
Kenya	Chusu	Medley and Kalibo (2007)
South Africa	Inkomankoma	Mhlongo (2019); Mhlongo and Van Wyk (2019)

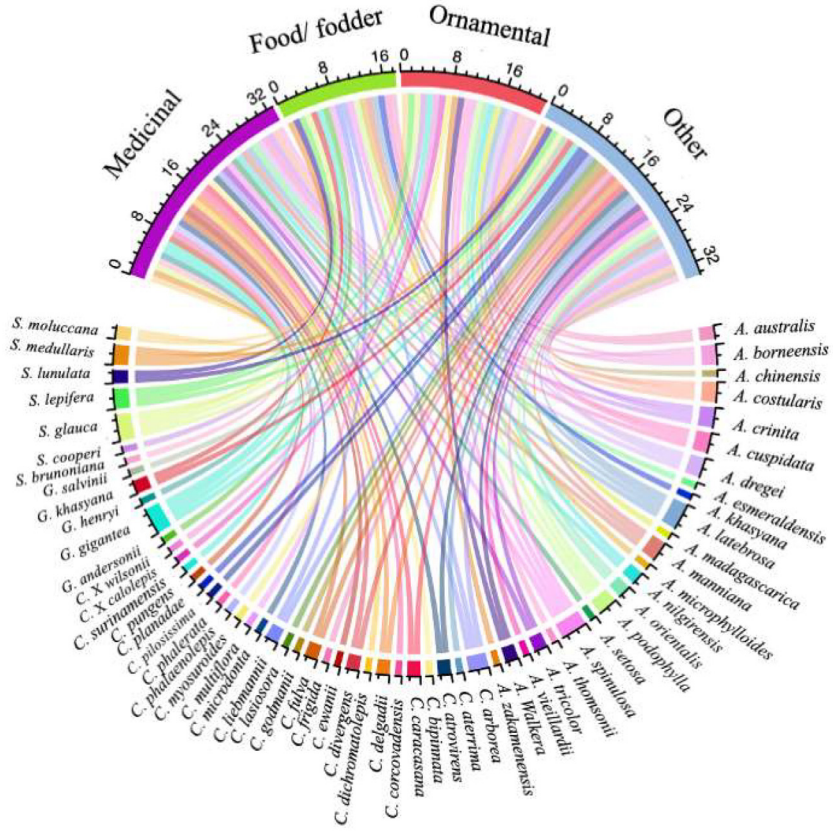

Fig.2. The chord diagram shows the 59 tree fern species utilized by various ethnic groups in 32 countries for medicinal, food, ornamental, and other purposes.

information collected through consultations with stakeholders via personal communications. We have excluded some traditional uses found on most web sources due to the absence of source information. After meticulous screening and analysis, we have categorized the results into four user categories: medicinal, food and animal feed, ornamental, and other uses (Fig. 2). The "other uses" category encompasses some uncommon local practices that are not widely observed today. However, such information not only reflects the close relationship between plants and people but also the potential for integrating this knowledge with modern practices.

Among these four categories, 33 species were found to have medicinal uses, 18 for food or fodder, 18 for decorative purposes, and 34 for various other uses (Fig. 2). The figure highlights the versatility of most species, with *A. spinulosa, G. gigantea* and *S. glauca* being particularly noteworthy for their wide range of applications. It is worth mentioning that we have observed the same species with different local names being used for various purposes by different ethnic groups within the same country. Moreover, the type of usage and vernacular names can vary significantly from one place to another and from one ethnic group to another. Table 2 illustrates how vernacular names and utility change based on geographical location and the ethnic community in Nepal and Bangladesh.

These observations emphasize that the geographical, socio-cultural, and demographic factors of a country or region intricately shape ethnobotanical knowledge. Furthermore, with the rapid evolution of socio-economic aspects within a country or region, there is a risk of losing this valuable traditional, time-tested knowledge from one generation to the next. Due to technological advancements and societal transformations, the current generation is increasingly moving away from traditional practices and failing to maintain a close and healthy relationship with nature. Therefore, exploring and conserving such unique knowledge rooted in traditional settings becomes of greater importance.

3.4.1. Medicinal uses of tree ferns

Exploring traditional medicine used by indigenous communities has continuously been increasing, with some traditional remedies gaining recognition as primary sources of drug discovery (Muhammad et al., 2020; Singh and Singh, 2012). While pteridophytes are less prevalent in traditional medicine than seed plants, Muhammad et al. (2020) reported that approximately 4% of all pteridophytes (442 species) have ethnomedicinal uses. On the other hand, tree ferns are being used in traditional medicine worldwide to treat various ailments, such as dysentery, body pain, antidiabetic, hepatoprotective, inflammation, respiratory issues, antihelmintic, high blood pressure, and headaches due to the presence of some important phytochemical components (Andi et al., 2010; Antonysamy et al., 2023; Julius and Andi, 2023). Additionally, Chaparro-Hernandez et al. (2022) also reported the role of *Cyathea* species in traditional medicine, highlighting the potential to treat skin, kidney, and eye infections and even degenerative diseases, such as cancer and diabetes. These medicinal properties are attributed to the bioactive molecules found within these remarkable tree ferns. In Fig. 3, we present a list of species used in traditional medicine along with their corresponding references for more detailed information. This compilation serves as a foundational resource for studying the important phytochemical properties and the integration of such knowledge into modern pharmacology.

Previous reports have revealed how tree ferns are used in the traditional medicine systems of various Asian communities, particularly in China, India, Nepal, and the Philippines. According to Kholia (2012), tree ferns have been used in the Indian traditional medicinal

Table 2
The diversity of ethnobotanical knowledge based on geographical locations within a same country and the ethnic communities involved.

Country	Description
Nepal	• In central Nepal, particularly from May to June, residents of *Kaski* district use young fronds of tree ferns as vegetables (Kunwar, 2017). The decoction of soft pith prepared with ghee is taken orally to treat body fractures and body aches (Adhikari et al., 2019). • The *Jirel* community in the Dolakha district of central Nepal applies a paste made from rhizomes to expel spines from the body (Karki et al., 2023). • In central Nepal, young fronds are used as pickles, while mature fronds are used as fodder (Thapa et al., 2017). • The community in *Lamjung* district has used the plant as fodder (Sing et al., 2020). • The *Lepcha* community of east Nepal drinks the water stored in the stump (stem) hole for a week to address urinary problems. The paste made from the stem is applied to treat wounds and swelling (Bhattarai, 2017). • In the *Ilam* district of east Nepal, young fronds are cooked to make curry and consumed during excessive bleeding during mensuration (Bhattarai and Khadka, 2016).
Bangladesh	• The *Bengali* people refer to *S. brunoniana* as "Brun brikkha", while the *Tanchogya* community calls it "Adibota". It is used as an ornamental plant to prepare medicine to treat fever. • *S. glauca* is known as "Kontami brikkha" by the *Bengali* people and is used as an ornamental plant by the *Tanchogya* and *Marma* communities. The "Chakma" community also utilizes this species to treat skin diseases. • *G. gigantea* is known as "Baro brikkha" by the *Bengali* people and "Baro adibota" by the *Tanchogya* community. The *Tanchogya* community uses it to reduce inflammation in the body, while it is considered an ornamental species among the *Tanchogya, Marma*, and *Chakma* communities. • *G. henryi* is known as "Henri brikkha" among the *Bengali* people. *Tanchogya* community uses the leaves of this species to treat wounds and sores and also utilizes it as a decorative agent. • The *Tanchogya* and *Chakma* communities use a rhizome paste of *A. spinulosa* to remove spines from the body.

Note: The information on the uses of tree ferns in Bangladesh collected by the author represents Bangladesh and the vernacular names based on Pasha and Uddin (2013).

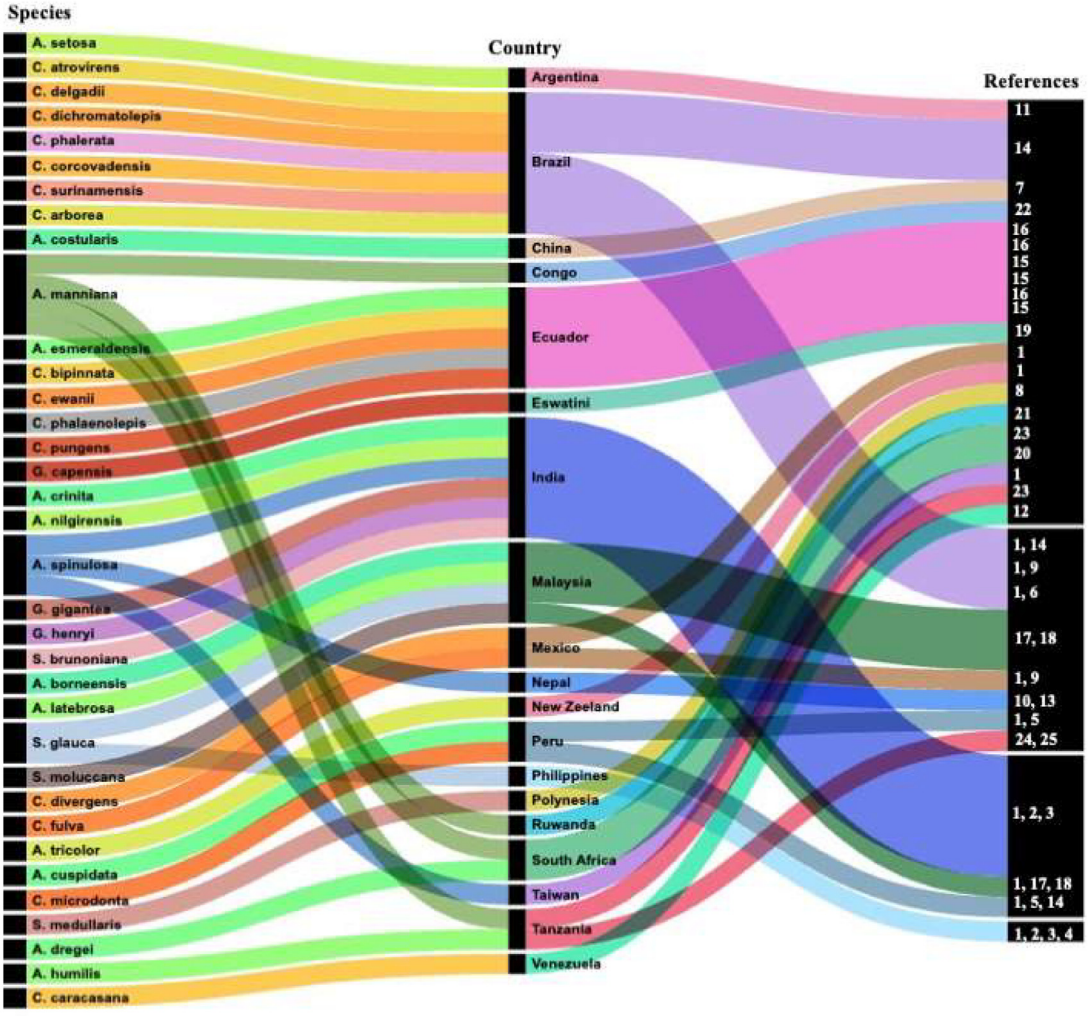

Fig. 3. Utilization of tree fern species in traditional healing across diverse cultural communities in selected countries.
References: 1- Chaparro-Hernandez et al. (2022); 2- Upadhyay et al. (2011); 3- Mishra & Behera (2020); 4- Dadang et al. (2020); 5-: Longtine & Tejedor (2017); 6 - Hort et al. (2008); 7- Lee et al. (2008); 8- Pétard (1986); 9- dos Santos Reinaldo et al. (2015); 10- Bajracharya & Bajracharya (2022); 11- Keller et al. (2015); 12- Guil-Guerrero & Campra (2009); 13- Adhikari et al. (2019); 14- de Medeiros et al. (2022); 15- Farrera Sarmiento (2011); 16- De la Torre et al. (2008); 17- Andi et al. (2010); 18- Julius & Andi (2023); 19- Dlamini (1981); 20- Hutchings et al. (1996); 21- Rwangabo (1993); 22- Bouquet (1969); 23- Fischer and Killman (2008); 24- Kokwaro, 2009; 25- Kokwaro, 1976.

system to treat various diseases, ailments, and injuries, although specific species are not mentioned. Mishra and Behera (2020) provide a detailed account of the medicinal uses of *S. glauca, G. gigantea* and *A. spinulosa.* There are also reports of tree ferns being used to treat health issues in domestic animals. Upadhyay et al. (2011) reported that a combination of stem powders from *A. spinulosa* and *Angiopteris helferiana* was given orally to cattle, including cows, buffalos, and goats, to address indigestion and hair loss caused by various factors. Dadang et al. (2020) report that 26% of surveyed locals used tree ferns as medicine in the Marilog District, Davao City of Sothern Philippines. The survey further reported that the liquid of boiling young fronds helps mothers shorten the duration of labor and improve postpartum recovery. Additionally, ferns were utilized as a home remedy for various health issues. However, it is crucial to understand the science behind these traditional treatments and identify the specific phytochemical compounds responsible for each instance.

The neotropics are recognized as one of the important centers for tree ferns. Information on using tree ferns as medicinal plants within regions of great ethnic diversity and indigenous cultures is limited. However, de la Torre et al. (2008) provide a long list of Ecuadorian tree fern species which used as medicinal plants. In Brazil, Cyatheaceae is used for various medicinal purposes, including combating infectious diseases (*C. arborea* against gonorrhea infections), neoplasms (*C. corcovadensis* for tumors), treating respiratory diseases (*C. atrovirens, C. corcovadensis, C. microdonta*, and *C. surinamensis*), addressing skin issues (*C. delgadii* for itchiness, allergies, and seborrheic dermatitis), and managing fever (*C. delgadii*). (de Medeiros et al., 2023). Chaparro-Hernandez et al. (2022) provided a comprehensive list of tree ferns with medicinal significance, which are used in various countries in South and Central America.

Among the species found in Africa, *Alsophila manniana* and *Alsophila dregei* stand out due to their well-known medicinal properties. These species have long been used by various indigenous communities, particularly as home remedies. *Alsophila manniana*, native to East Africa, has been utilized by the Chagga people and by German troops during World War I as an anthelmintic (Mabberley, 1997). It is also traditionally employed for the treatment of snake bites in Rwanda (Fischer and Killman, 2008). In Tanzania and South Africa, the young fronds of *A. manniana* are boiled and used to treat tapeworm infections, gastric disorders, and abdominal ailments (Lye et al., 2008). *Alsophila dregei*, locally known as Inkomankoma or Inkombandlela, is used to treat internal body pains, dermatological issues, reproductive system problems, and as a general tonic (Mhlongo, 2019; Mhlongo and Van Wyk, 2019). The roots have historically been used to deworm humans (Doke and Vilakazi, 1972). Gerstner (1941) and Roux (2003) report that the Zulu community in South Africa uses parts of the plant to make an infusion known as Inembe, which is given to pregnant women to ease childbirth. The Shambaa people of Tanzania prepare an infusion from broken stems of *Alsophila humilis* as an anthelmintic (Kokwaro, 2009; 1976). Since Africa is not only a center of tree fern diversity but also a hub of indigenous knowledge, future research should focus on the ethnobotany of all fern species, with particular emphasis on tree ferns.

Understanding the compounds responsible for the medicinal properties attributed to this plant group is of paramount importance. Chaparro-Hernandez et al. (2022) conducted a literature review to explore the potential of selected species of the family Cyatheaceae as a source of bioactive molecules. Several studies have strongly emphasized evaluating the phytochemical compounds in tree ferns that contribute to their medicinal properties (Talukdar et al., 2010; Longtine and Tejedor, 2017; Faizal et al., 2020). These findings highlight the value of traditional knowledge regarding the medicinal properties of tree ferns and how they foster a close and healthy relationship with plants. It will also serve as a valuable resource for today's pharmaceutical research and industry, especially in the development of new drugs.

3.4.2. Food and animal feed

Edible ferns are some of the most common wild food plants people collect worldwide. Fern stems (= rhizome), leaves (young fronds), shoots, and sometimes whole plants are used for food. Liu et al. (2012) reported 52 traditionally used taxa, and the potential number of edible fern species was estimated as 144 taxa in China alone. However, compared to other families, Cyatheaceae has fewer edible species. In Table 3, we provide information on species with food value worldwide.

Table 3
Edible (food/ feed) scaly tree ferns species reported worldwide.

Species	Edible part	Country/region	References
Alsophila australis	Pulp of the trunk/ also as animal feed (Pigs)	Australia	15
Alsophila cuspidata	Stem, tender leaves	Ecuador	19
Alsophila khasyana	The tender leaves of the species are used as fodder,	India	3
Alsophila latebrosa	Young frond	West-java	9
Alsophila manniana	Young frond	DRC	10
Alsophila microphylloides	Young frond	West-Papua	7
Alsophila podophylla	Starch in stem	Taiwan	16
Alsophila spinulosa	Stem	India	4
Alsophila spinulosa	Roots	India	4, 16
Alsophila spinulosa	Starch in stem	China	6
Alsophila spinulosa	Yong shoot and frond (as food and fodder)	Nepal	11, 12, 13
Alsophila vieillardii	Young frond	Vanuatu	8
Cyathea arborea	Stem, shoot	Brazil	5, 17
Cyathea liebmannii	Young frond	Vanuatu	8
Cyathea multiflora	Stem	Colombia	18
Gymnosphaera andersonii	Core of stem (substitute of wheat flour)	India	2
Gymnosphaera gigantea	Stem pith	India	14
Spheropteris glauca	Young frond	West-java	9
Sphaeropteris lepifera	Young frond, Starch in stem	Taiwan	16
Sphaeropteris lunulata	Young frond	Vanuatu	8
Sphaeropteris medullaris	Inner pulp of stalk/ stem	New Zealand	1

References: 1-Leach (2003); 2- Jain & Sastry (1983); 3- Kholia (2010); 4- Mishra & Behera (2020); 5- de Medeiros (2023); 6- Liu (2012); 7- Milliken (1992); 8- Ranker et al. (2022); 9- Suryana et al. (2018): 10- Termote et al. (2011). 11- Bhattarai & Khadka (2016); 12- Thapa et al. (2017); 13- Sing et al. (2020).14- Balkrishna et al. (2019); 15- Maiden (1889); 16- Huang et al. (2000); 17- Correa (1931); 18- Jimenez-Ortega & Palacios-Mosquera (2019); 19- De la Torre et al. (2008)

Fig. 4. The use of tree fern fronds for bamboo cooking is a traditional culinary practice among certain ethnic groups in Papua New Guinea. Photograph by Michael Sundue.

Similar to many other fern species, the young fronds of tree ferns are used as a vegetable and incorporated into various culinary recipes. The preparation methods, types of dishes, and consumption patterns can vary significantly from one community to another. For instance, Ranker et al. (2022) reported that the young fronds at the top of *A. vieillardii* are boiled in water for 5 minutes until they become soft and then consumed by some ethnic communities in Vanuatu. In the Ilam district of eastern Nepal, young fronds are cooked to make curry and consumed during excessive bleeding during menstruation (Bhattarai and Khadka, 2016). The fronds of certain tree fern species are used for "Bamboo cooking" by some tribal groups in Papua New Guinea. Fig. 4 shows a woman in Gahavisuka, Papua New Guinea, shredding tree fern leaves, and then she will stuff these leaves into bamboo tubes, mixing them with cut chicken. The tubes are then placed directly over a fire until the chicken and leaves are thoroughly cooked (Personal communication with Dr. Michael Sundue, Researcher, Royal Botanic Garden Edinburgh, UK).

Apart from utilizing fronds and shoots, it is noteworthy that there is evidence of the main stem and roots of tree ferns being used as food by some communities. Mishra and Behera (2020) reported that in India, people use the roots of *A. spinulosa* to make a local drink. In China, certain ethnic communities use the starch found in the stem of *A. spinulosa* to make feed (Liu et al., 2012). Additionally, Jain and Sastry (1983) report that some Indian ethnic groups use the core of the stem of *G. andersonii* as a substitute for wheat flour. Unfortunately, most of these traditional recipes are still in the hands of the elders of ethnic communities and are at risk of disappearing. Therefore, it is important to explore such knowledge, particularly focusing on diverse ethnic groups that still rely on wild edible plants in regions with a high diversity of tree ferns, such as the Neotropics, Madagascar, New Guinea, and Southeast Asia.

3.4.3. An ornamental plant

Tree ferns are particularly unique among other ornamentally valued pteridophyte species due to their captivating plant architecture, making them popular as ornamental plants. Consequently, their cultivation ranges from village houses to inclusion in indoor and outdoor landscape designs in luxury hotels and even airports (Fig. 5). Moreover, they are now widely cultivated in parks, gardens, along roadsides, and in other public spaces, all due to their enchanting beauty. However, the high user value and economic potential as ornamental plants have led to the collection of them from the wild and cultivating them in nurseries. This activity has become an income source for villages as well as a business venture for horticulturists. Suryana et al. (2018) reported the highest usage of tree ferns as ornamental plants among the community in the tree ferns of Sukamandi Village in West Java, Indonesia. Burrows (1990) reported that although still common in certain areas, *A. dregei* has been eradicated from some localities in Zimbabwe by collectors who prize it as a garden subject. Additionally, as Kholia (2010) reported, the hardy tree ferns of Sikkim are also favored by nurserymen from European and American countries. Here, we provide a list of widely used tree fern species as ornamentals worldwide (Table 4).

Since most of the tree ferns are protected by several local and international laws, collecting them from the wild and selling them is illegal in many countries. However, due to their demand in the floriculture industry, illegal collection from the wild continues. For example, in Sri Lanka, all native and endemic tree ferns are protected by the Fauna and Flora Protection Ordinance (FFPO) and have been further declared as threatened species in the National Red List – 2020, reflecting their significant threats. Since the general public is not aware of their biological and conservation values, as well as the legal background, they are collecting them for sale and cultivation in their homesteads. Nevertheless, it is essential to explore their economic potential and develop a management and utilization plan that aligns with a country's conservation policies.

3.4.4. Other uses

In addition to their three major uses mentioned earlier (medicinal, food, and ornamental), tree ferns serve various purposes for different ethnic groups (Fig. 6). These fascinating insights underscore the future potential of these plants and how traditional communities have benefited from plants that are now considered underutilized in today's context. After conducting a comprehensive review of various web-based literature sources and engaging in personal communication with key informants, we have compiled the following list of traditional uses of tree ferns, supported by appropriate examples.

3.4.4.1. Handicraft. Crafting handicrafts using tree fern trunks is a profitable business among some rural communities, although it is illegal in many countries. Traditional communities residing near forest reserves often collect tree ferns from the wild and use them to

Fig. 5. Use of tree fern species as an ornamental plant. A. Bali Botanic Garden, Indonesia. B. Auckland Botanic Garden, New Zealand. C. Hakgala Botanic Garden, Sri Lanka. D. Singapore Changi Airport. E, F & G. Local houses in Sri Lanka, Vietnam, and Taplejung district of Nepal, respectively. H. Tropical plant house, Alexandru Borza Botanical Garden, Romania. I. As a decorative plant along the road of Kinabalu Park headquarters, Sabah, Malaysia. Photographs by Ranil Rajapaksha (A - E), Van The Pham (F), Rijan Ojha(G), Crina Mocan (H), Andi Maryani (I).

create various items to support their livelihood. Suryana et al. (2018) and Dadang et al. (2020) have conducted comprehensive studies on the uses of tree ferns by local communities and provided information on crafting handicrafts as a means of contributing to their livelihoods. In Mexico, the adventitious roots of *C. godmanii* are used to create human figures reminiscent of pre-Hispanic times, as well as figures of different sizes representing animals like geese and small herons, known as “Maquique” (Cibrián and Sutherland, 2007). Eleutério and Pérez-Salicrup (2006) report that at least two tree fern species of the genus *Cyathea, C. divergens* var. *tuerckheimii* and *C. fulva*, are harvested by local artisans from tropical montane forest remnants in the Cuetzalan region of northeastern Puebla state (Mexico) to produce handicrafts used for garden ornamentation. *Alsophila dregei* is used for crafting handicrafts in South Africa (PlantZAfrica, 2024). [Additional species reported: *A. crinita, S. glauca*]

Table 4
List of the tree ferns used in landscaping.

Species	Country/region	References
Alsophila australis	Australia	Goller U Rybczynski (2007)
Alsophila borneensis	Malaysia	Andi et al. (2010); Julius and Andi (2023)
Alsophila costularis	China, Vietnam	Pu et al. (2023)
Alsophila crinita	Sri Lanka	Ranil et al. (2015)
Alsophila dregei	South Africa, Southern Africa	(PlantZAfrica, 2024)
Alsophila latebrosa	Malaysia, Vietnam	Andi et al. (2010); Julius and Andi (2023); Tran (2012)
Alsophila madagascarica	Madagascar	SelinaWamucii (2024a)
Alsophila nilgirensis	India	Abraham (2012)
Alsophila orientalis	West Java	Suryana et al. (2018)
Alsophila podophylla	Taiwan	Huang et al. (2014)
Alsophila spinulosa	India, Nepal, Taiwan	Mishra and Behera (2020); Huang et al. (2014); Hughes and Lamichhane (2017).
Alsophila thomsonii	DRC; Burundi; Tanzania; Angola; Zambia; Malawi; Zimbabwe; Mozambique,	Burrows (1990); Large and Braggins (2004); SelinaWamucii (2024c)
Alsophila walkerae	Sri Lanka	Ranil et al. (2015)
Alsophila zakamenensis	Madagascar	SelinaWamucii (2024b)
Cyathea myosuroides	México	Muñiz Díaz de León et al. (2007)
Cyathea x *calolepis*	Cuba	Caluff and Serrano (2002)
Cyathea x *wilsonii*	Cuba	Caluff and Serrano (2002)
Gymnosphaera gigantea	China, India, Vietnam	Wang et al. (2019); Yumkham and Singh (2011); Tran (2012)
Sphaeropteris cooperi	Australia	Goller and Rybczynski (2007)
Sphaeropteris glauca	Malaysia, Philippines, West Java, Vietnam	Andi et al. (2010); Julius and Andi (2023); Coritico et al. (2014); Suryana et al. (2018); Tran (2012)
Sphaeropteris lepifera	Taiwan	Huang et al. (2014)
Sphaeropteris moluccana	Malaysia	Andi et al. (2010); Julius and Andi (2023)

3.4.4.2. Fertilizer. Compared to other pteridophyte species, tree ferns possess a relatively high above-ground biomass, which is a beneficial characteristic for formulating organic fertilizer. Therefore, the entire tree can be used to make fertilizer. Dadang et al. (2020) reported that 60% of the surveyed communities in the Marilog district, Southern Philippines, use *S. glauca* to make fertilizer.

3.4.4.3. Raw materials for game tools. Suryana et al. (2018) reported that the stem pith of *S. glauca* and *A. orientalis,* which is removed from the trunk, is made into round-shaped balls used to play a traditional game in some communities in West Java. Similarly, Ranker et al. (2022) reported that the ancestors of some communities in Vanuatu used the stem of *S. lunulata* to make balls for playing games.

3.4.4.4. Firewood. Ranil et al. (2004) and Ranil and Bussmann (2021) have provided evidence of the use of *A. walkerae* as firewood by the elders of traditional communities around the Kannaneliya Man and Biosphere Reserve in Sri Lanka. The peaty wood of *C. arborea* burns for a long time and is used to carry fire from one place to another, as mentioned by (May, 1978). The African species, *A. manniana* is also used as firewood (Yamada, 1999).

3.4.4.5. Making fences and gates. Ranil and Bussmann (2021) report that the robust stem of mature tree fern trunks serves as materials for constructing fences around traditional houses and flower beds in landscaping. Additionally, Bhattarai et al. (2017) and Thapa et al. (2017) have reported the use of tree fern trunks in making entrance gates (locally known as “Tagaro”) for traditional houses in Nepal. The Kikuyu community of Kenya use the stem of *A. manniana* as fencing posts because of its toughness (Gachathi, 2007). [Additional species reported: *A. walkerae, A. cuspidata, A. spinulosa, A. crinita, C. delgadii, C. liebmannii*].

3.4.4.6. Supportive structures. Tree fern trunks are employed as a supportive structure instead of wooden poles in certain cultivation practices. Kholia (2010) and Ranil et al. (2004) have reported their use in the cultivation of betel nut and black pepper. [Additional species reported: *A. walkerae, G. gigantea*].

3.4.4.7. Construction materials. Strong and well-matured tree fern trunks serve as construction materials. These trunks are used to make pillars for cattle shades, as mentioned by Kholia (2010). According to Bhattarai (2017), such pillars are also used for constricting houses in Nepal. Furthermore, in some local villages in the Solomon Islands, tree fern trunks are still employed to build small houses, kitchens, and different kinds of shelters (as personal communication with Mr. Cheng-Wei Chen, Researcher, Taiwan). The waxy caudex of *C. arborea*, a common tree fern found in the West Indies, Mexico, and Venezuela, is dried and used as timber by the Caribs, as documented by May (1978). Espinosa Jiménez et al. (2021) reported in their scientific paper on the use of *C. caracasana* stems in housing construction in Colombia particularly as poles and beams. *Alshophia manniana* is also used as constructing materials for building local house (Yamada, 1999). [Additional species reported: *A. spinulosa, A. tricolor, C. aterrima, C. frigida, C. lasiosora, C. pilosissima, S. medullaris*].

3.4.4.8. As a growth medium. The stems of tree ferns find widespread use worldwide as a substrate or growth medium for orchid cultivation (Pham, 1999; Cibrián and Sutherland, 2007; Yumkham and Singh, 2011; Mishra and Behera, 2020; Ranil & Bussmann (2021); de Medeiros, 2022) They are also employed as substrates for cultivating epiphytic ferns (Kholia 2010). The fibrous trunk of *A. manniana* is used by Kikuyu community as a substrate for orchid’s cultivation in Kenya (Gachathi, 2007. *Alsophila dregei* is used as substrate of orchid cultivation in South Africa (PlantZAfrica, 2024). [Additional species reported: *A. borneensis, A. chinensis, A. costularis, A. crinita, A. latebrosa, A. podophylla, A. spinulosa, C. arborea, C. atrovirens, C. divergens, S. glauca, S. lepifera, G. gigantean, G. salvinii*).

3.4.4.9. Bedding materials. Old leaves of *G. khasyana* are used as bedding materials for cows, as mentioned by Kholia (2010). Additionally, Dorji et al. (2022) reported the use of *A. spinulosa* as bedding materials in animal sheds.

3.4.4.10. Roofing materials. Tree fern fronds are utilized as roofing materials in both houses and animal sheds. *A spinulosa* is used as roofing animal sheds (Dorji et al., 2022). Joshi (1997) also reported the use of *A. spinulosa* as thatching roofs in India.

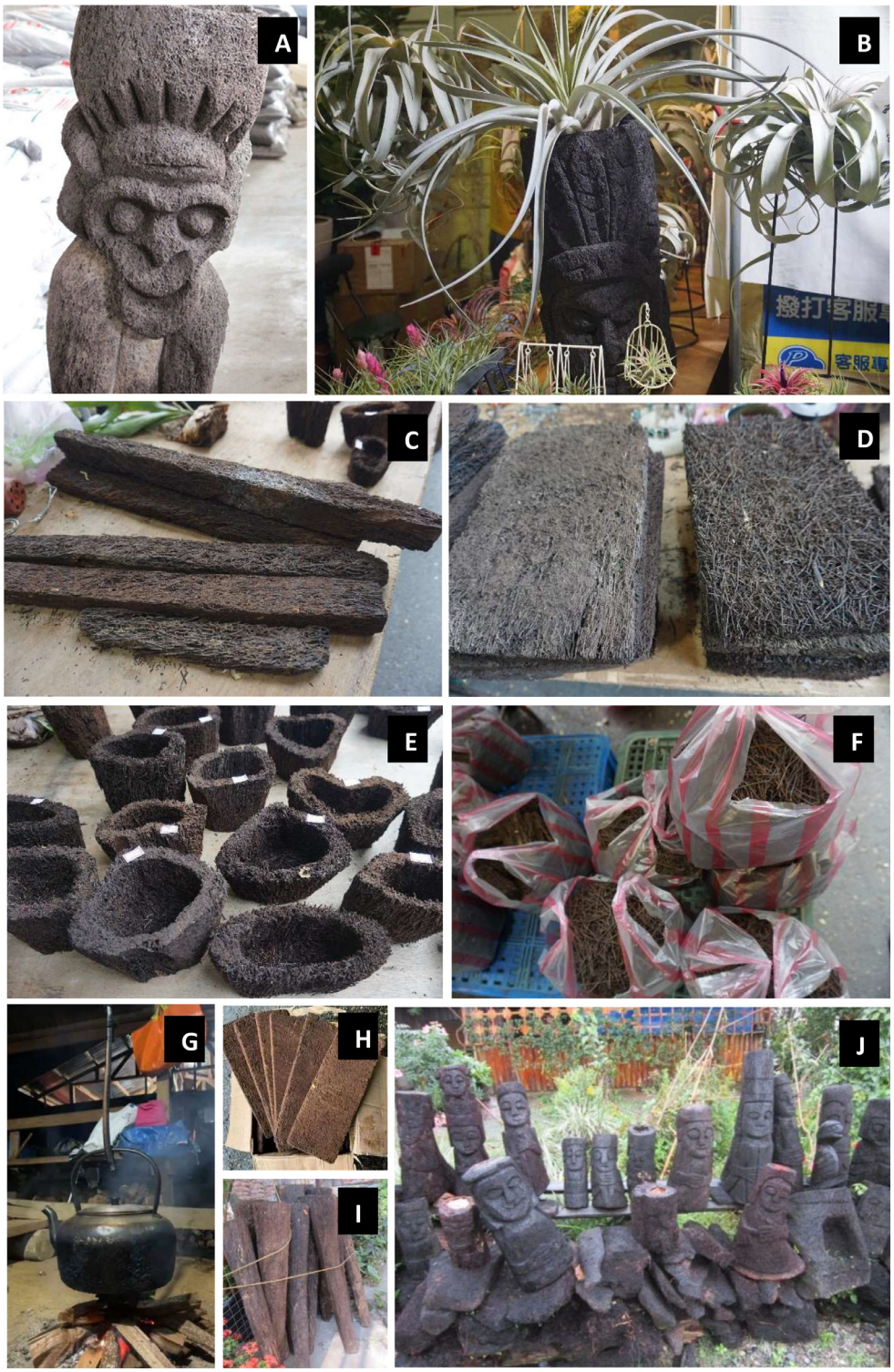

Fig. 6. Different products and uses of tree ferns. A- F. Different products available at the Jiannguo Holiday Flower Market, Taipei, Taiwan. G. A strong stipe-branch of *S. glauca* use to hold or hang a kettle in Sabah, Malaysia. H. *A. latebrosa* trunk use as a slabs/boards in Malaysia. I. Tree fern trunks used in constructions (Philippines). J. Handicrafts made from tree fern trunks (Philippines). Photographs by Yao-Moan Huang (A-F), Andi Maryani (G,H), Fulgent Coritico (I,J).

3.4.4.11. Making pillows. Ranker et al. (2022) reported that the brown scales on the leaf petiole bases of *A. vieillardii* are collected and then stuffed into cloth bags to make pillows.

3.4.4.12. Making fishing and hunting spears and arrows. *S lunulata* has been historically used for crafting fishing and hunting spears among traditional communities Ranker et al. (2022). This involved taking 4–5 pencil-shaped pieces of stem and tying them to the end of a piece of wild cane using a bush vine. Then, they would sharpen the tips of these pieces and use them for fishing and hunting. Additionally, they would use 1–2 pencil-shaped stem pieces to make arrows and sharpen them. The tips are said to be very strong (Ranker et al., 2022).

3.4.4.13. Rituals. Tree ferns have held ritual significance in various indigenous communities. For instance, in West Papua, tree ferns have been used ritually by indigenous communities to protect women and children while men collect Pandanus fruits in the mountains (Milliken, 1992). Some locals in the Marilog District, Davao City, locals create "Anito" (human-shaped carvings) made from the stem of *S glauca.* These carvings symbolize a rich cultural heritage and are believed to protect the community from drought, hunger, and pestilence (Dadang et al., 2020). The Xhosa people of South Africa use *A. dregei* to make an infusion called isikhomakhoma to neutralize the effect of witchcraft (Hutchings et al., 1996; Roux, 2003).

3.5. Tree ferns are multipurpose species

Among angiosperms, multipurpose species are abundant and widely incorporated into agroforestry and integrated farming systems, mainly due to their potential to provide more than one use or service. In contrast, ferns are generally not considered multipurpose due to their limited utility. Present-day ferns usually have limited economic potential and user value compared to seed plants. However, their potential, along with their economic, environmental, and social significance has not yet been fully understood. Therefore, they remain an underutilized and neglected group of plants. Tree ferns are remarkable for their versatility among pteridophytes as they offer multiple uses to various communities. We have discussed the diverse range of applications attributed to indigenous, traditional, and local communities around the world. In conclusion, we refer to tree ferns as "multipurpose species" because of their ability to address fundamental community needs such as food, medicine, and shelter. (Fig. 7).

3.6. Application of ethnobotanical knowledge

The application and integration of indigenous and local community knowledge with modern science have been incorporated into the United Nations' sustainable development goals due to their potential to provide information, methods, and practices for sustainable ecosystem management (Srivastava et al., 2023). While some ethnobotanical uses may no longer be considered acceptable today due to their adverse effects on natural populations, it is important to recognize that some of these traditional uses can still be useful to promote the concept of "conservation through utilization". Therefore, it becomes crucial to comprehensively understand their user value and significance. By doing so, we can effectively advocate for their responsible use as beneficial plants, not only for the economic benefit of traditional communities but also for their potential contribution to the broader national economy.

Though this group of plants has a growing demand due to its unique tree architecture and attractive foliage, only a few species are popular in the field of floriculture. Since these tree ferns have specialized ecological requirements and habitat characteristics, the species need to be investigated for their suitability for cultivation under ex-situ conditions. Growing requirements, methods of propagation, and growth and development need to be specifically investigated. Currently, some countries utilize a few selected species in landscaping, such as home gardens, parks, hotels, restaurants, etc. Tree ferns are an integral component of botanical gardens worldwide. They serve for outdoor landscaping and have a high potential for growing in indoor environments (Fig. 5). However, it is important to understand their ecological and habitat requirements and acclimatization potential before introducing them to the floriculture industry. Fig. 8 shows the potential and how *A. crinita* fits with the objectives of gardening. de Winter and Amoroso (2003) have proposed a few criteria that

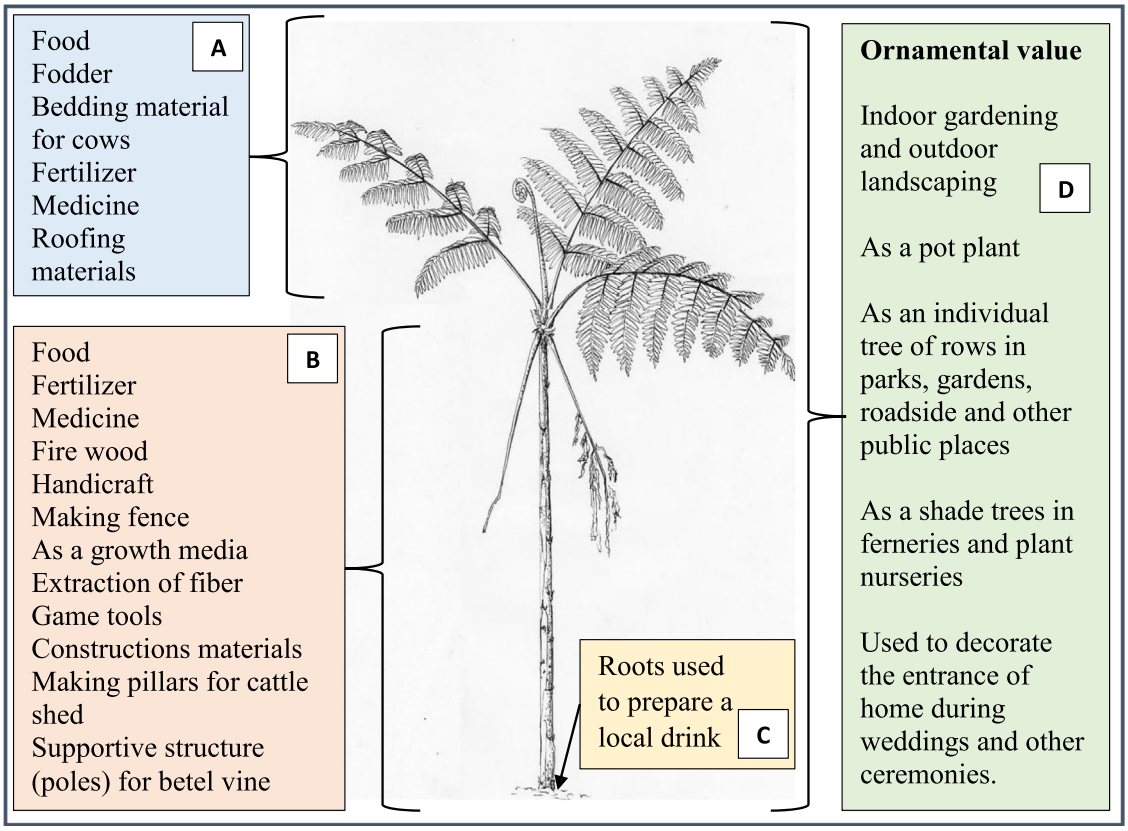

Fig.7. The multiple benefits provided by tree ferns (A- frond = leaf), B- trunk (= stem, rhizome), C- roots, D- whole plant).

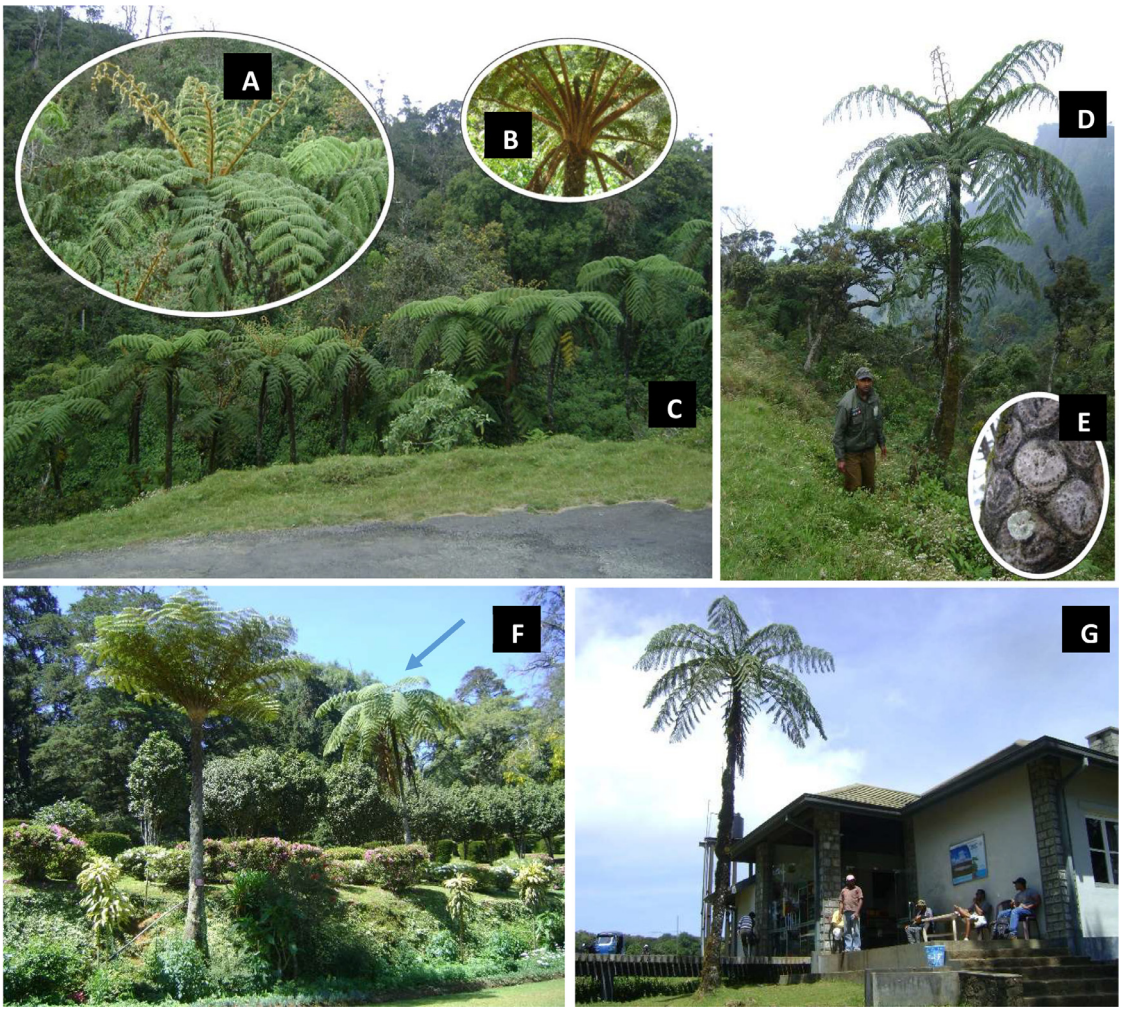

Fig. 8. *Alsophila crinta*, a native species to high altitude areas of South India and Sri Lanka. A. a crown with densely crowded fronds; B. a collection of stipe bases; C. a naturally grown population which shows the potential of avenue planting; D. a well-grown mature individual in the wild; E. scars on tree trunk; F. an individual grown in a city park; G. a plant grown nearby a hotel. Photographs by Ranil Rajapaksha.

pteridophytes should fulfill when a particular species is cultivated as an ornamental plant. Table 5 validly justifies the potential of tree fern species as ornamentals in agreement with such criteria.

Several authors have reported that local communities in certain areas maintain tree fern nurseries intending to supply them for commercial purposes and cater to tourists. The numerous large-scale nurseries producing tree ferns through conventional propagation methods and micropropagation techniques show that demand for tree ferns exists among gardeners and floriculturists worldwide. Local communities in certain countries engage in the collection of tree fern stems from the wild for crafting, as highlighted by Eleutério and Pérez-Salicrup (2006), Suryana et al. (2018) and Dadang et al. (2020), and. Furthermore, a significant demand exists for tree fern trunks among orchid and fern growers, who utilize them as a substrate for the commercial cultivation of epiphytic orchids and ferns. Hence, it becomes vital to explore the potential of cultivating tree ferns on a large scale for commercial purposes.

Although traditional communities once relied on tree ferns for food and medicinal needs, they are now unlikely to be used for such purposes by communities outside indigenous groups living in highly remote or geographically isolated areas. Several studies emphasized that importance of investigating tree ferns' propagation methods, growth parameters, and agronomic operations to enable large-scale commercial cultivation (Bernabe et al., 1999; Reis Moura et al., 2012;

Table 5
Potential of tree ferns as ornamental plants according to the criteria proposed by de Winter and Amoroso (2003).

Criteria	Justification
1. Densely placed fronds which give them a packed foliage appearance	Frond shape ranges from simple leaves to tri-pinnate and fronds are densely arranged as a crown.
2. Small to medium size	The plant size ranges from 1 m *Alsophila sinuata* (Sri Lanka) to 20 m *Sphaeropteris excelsa* (Norfolk Island).
3. An ever-green habit	Except for *Alsophila firma* which is deciduous (Mehltreter and García-Franco, 2008), other species are evergreen.
4. At least one unique characteristic that makes them special	Most species consist of large fronds and pronounced upright tree trunks.
5. Should be able to stand adverse climatic conditions	Tree ferns are predominantly found in moist, shaded habitats within forest ecosystems (Chiu et al., 2015). However, certain species are remarkably adaptable and can thrive in a diverse range of climatic and soil conditions. These versatile tree ferns can be successfully cultivated in both indoor and outdoor environments.

Fig. 9. The Cyatheaceae species in the Philippines face various threats. A. Degradation of natural habitats of tree ferns. B. Overexploitation of the resources. Photographs by Fulgent Coritico.

Vargas and Droste, 2014; Huang et al., 2000). This would provide knowledge on the production of raw materials for the ornamental industry, handicraft production, and growth media for orchid cultivation. In the meantime, it is also essential to explore uncommon uses of tree ferns to assess the potential for integration into other industrial applications.

Because tree ferns are unique and significant in the plant kingdom in terms of ecology, biogeography, and evolution, commercialization poses a significant challenge. For example, in the Philippines, a total of 25 species are endemic to the country, and it shows that the high endemism of scaly tree ferns on the Island is due to the distinct biogeographical location of the Island. Van Welzen (2011) stated Wallacea (that includes the Philippines) is a distinct area because it comprises many endemics, drought-tolerant floristic elements. Among the species, *S. glauca* and *S. lepifera* are commonly harvested because they usually grow in lower elevation and open areas. These species are commonly harvested for handicraft making, medium to grow other plants, and serve as house posts. These tree ferns play an important ecological role in ecosystems because they serve as the habitat of many mosses, ferns, and lycophytes. Most importantly, tree fern trunks are the only habitat of the most primitive vascular plants, *Tmesipteris zamorarum* and *Psilotum complanatum*. This account highlights the unique role of tree ferns in nature and the essential considerations before popularizing them. Also, the overexploitation of species from their natural habitat can lead to extinction.

It is important to mention here that tree ferns are legally protected by several national and international laws. The majority of tree ferns are listed in Appendix II of CITES, which means all species are not necessarily currently threatened with extinction, but may become so unless trade is closely controlled. Still, their trade must be controlled to avoid utilization that is incompatible with their survival (Dadang et al., 2020). This indicates that transporting most species from one country to another violates international law. Burrows (1990) noted that while *A. dregei* remains common in some regions, it has been eradicated from certain localities in Zimbabwe due to collectors who highly value it as a garden plant. While some countries legally protect tree ferns, there are provisions for multiplying or propagating them ex-situ and selling them under specific conditions. However, the development of such management and conservation plans should always be aligned with the rules and regulations of each country. Additionally, these plans should aim to minimize or eliminate damage to natural populations.

Apart from over-exploitation, habitat degradation is one of the most destructive activities affecting tree fern populations worldwide (Ranil et al., 2017; Eleutério and Pérez-Salicrup, 2009; Mishra and Behera, 2020). The impact of habitat degradation on tree ferns has not been extensively studied. The authors of this publication, representing several countries, have observed firsthand the extent of habitat degradation and its impact on species populations. Fig. 9 illustrates the degradation of natural habitats and the effects of overexploitation on tree ferns in Mindanao Island, Philippines. Additionally, only a few countries have proposed conservation status for tree ferns in their National Red Lists. In many countries where tree ferns are prevalent, their conservation status has yet to be assessed. Since this is the foundation for setting conservation and management guidelines, immediate priority should be given to identifying the root causes and assessing the level of threats, followed by assigning conservation status. Additionally, the traditional communities around tree fern-rich areas across the globe need to be aware of the biological significance, conservation value, and sustainable utilization of tree ferns.

4. Conclusion

With the inclusion of traditional, indigenous, and local knowledge in the United Nations Sustainable Development Goals, there is a growing interest among ethnobotanists in exploring and documenting unique knowledge linked with traditional communities worldwide, particularly in the Global South, fostering a North-South dialogue. This review highlights the importance of integrating indigenous and local knowledge with modern science for the sustainable utilization and effective conservation of tree ferns.

Except for a few Asian countries, most of the tree fern-diverse countries have not been adequately studied on ethnobotanical knowledge linked with traditional communities and tree ferns. Most current and previous studies have primarily focused on taxonomy, phylogeny, and ecological aspects. Thus, it is urgent to prioritize these countries, particularly in the tropics, and initiate systematic studies to explore ethnobotanical knowledge associated with tree ferns before it disappears from traditional communities. Our review provides baseline information to initiate further studies on the ethnobotanical aspects of tree ferns worldwide, supporting their responsible use and conservation.

Utilizing wild species for commercial purposes presents significant challenges, but it can become a realistic endeavor through the implementation of a comprehensive strategic plan designed to address these challenges systematically. The results of an ethnobotanical survey are more meaningful when the knowledge gathered can be effectively integrated into modern-day practices. Such integrated plans support the conservation and utilization of traditional knowledge and align with the widely applied integrative conservation approach (ICA) for preserving biological diversity. Since

community involvement is one of the key elements of ICA, future studies should be directed toward exploring, conserving, and utilizing ethnobotanical knowledge associated with various ethnic communities worldwide, with a focus on integrating this knowledge into modern scientific practices. We are confident that the insights from our study will offer valuable guidance for shaping future strategies in the management, conservation, and utilization of this distinct plant group.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of competing interest

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CRediT authorship contribution statement

Ranil Rajapaksha: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ruwan Chamara:** Writing – review & editing, Visualization, Software, Investigation, Data curation. **Yao-Moan Huang:** Writing – review & editing, Investigation, Data curation. **Rijan Ojha:** Writing – review & editing, Investigation, Data curation. **Caroline Modena de Medeiros:** Writing – review & editing, Investigation, Data curation. **Andi Maryani A. Mustapeng:** Writing – review & editing, Investigation, Data curation. **Fulgent Coritico:** Writing – review & editing, Investigation, Data curation. **Taherul Islam:** Writing – review & editing, Investigation, Data curation. **Liuder Isidoro Rodríguez Coca:** Writing – review & editing, Investigation, Data curation. **Rainer W. Bussmann:** Writing – review & editing, Validation, Data curation. **Peris Kamau:** Data curation, Investigation, Writing – review & editing.

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