
**Faculty of Resource Science and Technology**

# Diversity and Systematics Study of Tribe Alpinieae (Zingiberaceae) in Sarawak

**Salasiah Mohamad**

**Doctor of Philosophy**
**2021**

# Diversity and Systematics Study of Tribe Alpinieae (Zingiberaceae) in Sarawak

Salasiah Mohamad



A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

(Plant Science)

Faculty of Resource Science and Technology
UNIVERSITI MALAYSIA SARAWAK
2021

## ACKNOWLEDGEMENT

I would like to take this opportunity to acknowledge those who have contributed directly and indirectly to this thesis.

My deepest gratitude goes to Dr. Qammil Muzammil Abdullah @ Meekiong Kalu for the supervision given during my period of study at the Universiti Malaysia Sarawak. I am also indebted to my co-supervisor, Assoc. Prof. Dr. Alona Cuevas Linatoc from Universiti Tun Hussein Onn Malaysia for her endless support and advice throughout this study. I would also like to convey my appreciation to Dr. Axel Dalberg Poulsen and Dr. Mark Newman from the Royal Botanic Gardens, Edinburgh, for sharing their vast knowledge on gingers, providing constructive criticism and botanical inputs.

I would like to thank the staff of the faculty especially the SEM lab, the GC-MS lab, and the ecology lab for their technical help and support. I am also indebted to my colleagues especially Ivy, Karimah, Alvin, and Vincent for their great assistance during the fieldwork. Special thanks to Prof. Emeritus Datin Dr. Maryati Mohamed for continuing to encourage and endlessly supporting me to further my study in plant taxonomy. I also owe my sincere appreciation to Universiti Tun Hussein Onn Malaysia and the Faculty of Applied Science and Technology for the Skim Tenaga Akademik Baru awarded to me during the third year of my study.

My deepest appreciation goes to my husband, my son, and my family for their incredible support and prayers throughout this journey. Without these people, the thesis would have never been possible. Thank you very much.

## ABSTRACT

Family Zingiberaceae formed an important herbaceous layer in the tropical forests of Borneo. From the phylogenetic view, certain genera of the problematic tribe Alpinieae are non-monophyletic and in need of more taxonomic evidence to support the classification. This study demonstrates how the morphological, anatomical, palynological, and phytochemical evidences, correlated to the proposed phylogenetic data, taking representatives from the Bornean species. Furthermore, the rapid deforestation of the forests in Sarawak has also urged the assessment of the distribution and diversity of the species. Overall, 45 taxa from 11 genera were identified, including a newly described species and variety, *Sundamomum corrugatum*, and *Plagiostachys strobilifera* var. *conica,* respectively. Comprehensive morphologies of the fruit, anther crest, anther dehiscent, stigma, ostiole, labellum, lateral staminodes, and leaf sheaths were important in delimiting the species and genera in the tribe. The studied species were conveniently divided into two major groups based on the exine sculpturing of the spheroidal pollens, either psilate as in *Etlingera* and *Hornstedtia*, or echinate as in the remaining genera. Likewise, vegetative anatomical assessment unveiled informative characteristics in distinguishing the species. Phytochemical study of the rhizomes essential oils further revealed the major and specific components that characterised each studied cluster. Additionally, Lambir Hills National Park recorded the most diverse and stable area for Alpinieae species that could function as an important in-situ conservation area in Sarawak.



**Keywords:** Alpinioideae, anatomy, chemotaxonomy, diversity, palynology

***Kepelbagaian dan Kajian Sistematik Suku Alpinieae (Zingiberaceae) di Sarawak***

## *ABSTRAK*

*Keluarga Zingiberaceae membentuk lapisan herba penting di hutan tropika Borneo. Daripada pandangan filogenetik, genus tertentu dari suku Alpinieae ialah bukan monofiletik dan memerlukan lebih banyak bukti taksonomi untuk menyokong klasifikasinya. Kajian ini menunjukkan bagaimana bukti-bukti morfologi, anatomi, palinologi dan fitokimia berkorelasi dengan data filogenetik yang dicadangkan, mengambil wakil daripada spesies-spesies Borneo. Tambahan pula, penebangan hutan yang pesat di Sarawak juga mendesak penilaian mengenai taburan dan kepelbagaian spesiesnya. Secara keseluruhan, 45 takson daripada 11 genus dikenal pasti, termasuk spesies dan varieti yang baru dijelaskan, Sundamomum corugatum, dan Plagiostachys strobilifera var. conica. Morfologi komprehensif buah, balung anter, bukaan anter, stigma, ostiol, labelum, staminod sisi, and sarung daun menandakan peranan penting dalam membatasi spesies dan genus di suku tersebut. Spesies yang dikaji secara mudah dibahagikan kepada dua kumpulan besar berdasarkan pengukiran debunga sferoidnya, sama ada psilat seperti di Etlingera dan Hornstedtia, atau ekinat seperti di genus selebihnya. Begitu juga, penilaian anatomi vegetatif menunjukkan ciri-ciri bermaklumat dalam membezakan spesies. Kajian fitokimia minyak pati rizom menunjukkan komponen utama dan spesifik yang mencirikan setiap kluster yang dikaji. Selain itu, Taman Negara Bukit Lambir merekodkan kepelbagaian tertinggi dan stabil untuk spesies Alpinieae yang dapat berfungsi sebagai kawasan pemuliharaan in-situ yang penting di Sarawak.*

***Kata kunci:*** *Alpinioideae, anatomi, kemotaksonomi, kepelbagaian, palinologi*

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF SYMBOLS

| | |
|---|---|
| ° | degrees |
| °C | degree Celsius |
| " | inches |
| > | larger than |
| ≥ | larger than or equal to |
| ± | more or less |
| ! | seen by author |
| < | smaller than |
| ≤ | smaller than or equal to |
| µm | micrometre |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AAU | Herbarium of Aarhus University |
| aff. | akin to |
| BM | Herbarium of the British Museum of Natural History |
| BO | Herbarium Bogoriense (Indonesian Institute of Sciences) |
| C | Herbarium of Natural History Museum of Denmark |
| *ca.* | around |
| cf. | compare to |
| cm | centimetre |
| diam. | diameter |
| E | Herbarium of the Royal Botanic Gardens Edinburgh |
| et al. | and others |
| FI | Herbarium of the Natural History Museum Italy |
| fl. | flowering |
| FR | Forest Reserve |
| fr. | fruiting |
| HUMS | Herbarium of Universiti Malaysia Sarawak |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| K | Herbarium of the Royal Botanic Gardens Kew |
| KEP | Herbarium of the Forest Research Institute Malaysia |
| KYO | Herbarium of Kyoto University |
| L | Herbarium of the Naturalis Biodiversity Center |
| m | metre |

| | |
|---|---|
| mm | milimetre |
| nom. illeg. | illegal name |
| nom. nud. | invalidly published name |
| NP | National Park |
| P | Herbarium of the Muséum National d'Histoire Naturelle |
| p.p. | partly |
| pH | Measure of acidity or alkalinity |
| s.l. | in the broad sense |
| s.n. | without a number |
| s.s. | in the narrow sense |
| SABC | Herbarium of the Sarawak Biodiversity Centre |
| SAN | Herbarium of the Sabah Forestry Department |
| SAR | Herbarium of the Sarawak Forestry Department |
| SING | Herbarium of the Singapore Botanic Gardens |
| sp. | species (singular) |
| spp. | species (plural) |
| st. | sterile |
| subsp. | subspecies |
| TPA | Totally Protected Area |
| var. | variety |
| WRSL | Herbarium of Wroclaw University |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Study

Borneo is the world's third largest island and the second largest island in the Malay Archipelago with approximately 746,000 $km^2$ of total land area. The island constitutes of Kalimantan, Indonesia, on the southern and eastern parts (539,460 $km^2$; 72.6%), Malaysian states of Sarawak and Sabah which lie on the central-western part (124,451 $km^2$; 17% of the island) and the northern section (73,619 $km^2$; 10%) respectively, and the State of Brunei Darussalam that occupies the northwest coast of the island with just 5,745 $km^2$ of land area (Lamb et al., 2013).

In the Pleistocene epoch, about 2.58 million to 11,700 years ago, the Riau Pocket which consisted of the west coast part of Borneo (West Kalimantan, Sarawak, and Brunei), part of Peninsular Malaysia and Riau Islands was a tropical rainforest refuge (Bird et al., 2005; Lamb et al., 2013). During this epoch, the polar ice caps repeatedly melted resulting in rises and falls of the global sea level. During colder period and when the sea level fell, Borneo Island became part of Sundaland (which includes Malay Peninsula, Borneo, Java, and Sumatra), and during this time the flora have dispersed over the landmass and adapted to continual changing environments and favourable habitats (Bird et al., 2005). During the meltdowns, the sea levels rose by 50 m and Borneo became isolated. The dramatic changes of the land and sea on Sundaland might be one of the reasons for the high floral endemism in Borneo.

According to the most comprehensive and continuously updated database, 325,000 of flowering plants from 350,000 of the total accepted species have been recorded so far, by which the Asian region holds the highest record of new species discovered in 2019 (Antonelli et al., 2020; WCVP, 2020). About 5 – 6% or 10,000 – 12,000 of the total world's plants species are native to Borneo and, in particular, nearly 40 – 50% of the species is endemic to the island (Wong, 1995; WCVP, 2020; POWO, 2020). Following the current report by Cámara-Leret et al. (2020) on the floristic assessment of Papua New Guinea, Borneo is the world's third most floristically diverse island that supports 11,165 described species, after Madagascar with 11,488 species, and the largest, Papua New Guinea with 13,634 described species.

Relative to Malaysian flora, Peninsular Malaysia holds over 8,300 species of vascular plants (Saw & Chung, 2015). Whereas for Sarawak and Sabah, accurate figures on the vascular plants are scarce and have been estimated to be between 9000 to 15,000 species (Merrill, 1950; Wong, 1995) or approximately 11,500 species if based on the estimation provided by Tree Flora of Sabah and Sarawak, which contained 38.5% more species than Malaya's (Saw & Chung, 2015).

Compared to Peninsular Malaysia, the collection history of flora from Sabah and Sarawak were less intense in the early years. Summary of the detailed collection history in Borneo has been discussed by Wong (1995) in the introductory section of the Tree Flora of Sabah and Sarawak Volume I. The earliest collection of plants species in Borneo started as early as 1822 by George Müller, who was the acting Resident in Dutch West Borneo in the vicinity of Kapuas and Pontianak, followed by several explorers who had a keen interest in studying rare tropical plants or for horticultural value. Subsequently, in 1854 - 1856, Alfred

Russel Wallace had also collected ferns from Sarawak, particularly in Simunjan and Sadong Rivers, and between 1865 and 1867, the well-known Italian botanist, Odoardo Beccari, explored several more areas in Sarawak covering Kuching, Matang, Sarawak River, Batang Lupar, Bintulu, and Rejang valley (Wong, 1995). Subsequent plants collections covering more areas in Borneo and systematic account have continuously been made by various researchers since then, such as by Merrill (1950), which provided better understanding of the vast flora of Borneo.

Karl M. Schumann (1904), through his book *Das Pflanzenreich* on the world's Zingiberaceae, provided one of the earliest real revision that included Beccari's collections from Sarawak. In 1909, H. N. Ridley, after his documentation of *Scitamineae in Peninsular Malaysia* (Ridley, 1899), had added more subsequent species from Borneo based on his own collections along with Haviland's and Hewitt's (Ridley, 1909). Rosemary M. Smith further published more detailed regional revisions of Zingiberaceae in Borneo, firstly focusing on Gunung Mulu National Park, Sarawak, (Smith, 1982, 1984) and later expanded to include the whole island (Smith, 1985, 1986, 1988, 1989).

Warm equatorial climate with little seasonality, hot and humid throughout the year, provides suitable condition for the growth and survival of tropical rainforest. Other than mixed dipterocarp forest, Sarawak forest formations are also majorly composed of alluvial forest, heath forest, and forest over limestone. To safeguard its biodiversity, Sarawak has gazetted 8% of the total land or 4,209,053 ha as permanent reserves that comprise 44 Protected Forests, 47 Forest Reserves, 18 Communal Forests, and 1 Government Reserve up until 2018 (Forest Department Sarawak, 2020).

However, increasing trends of irresponsible deforestation and land conversion for plantation and other developmental purposes seemed inevitable, which have led to major loss of the many priceless species (WWF, 2020). In many cases, exploitation for commercial purposes is given priority over scientific study, leading to the loss of often undescribed species. Hence, as the clock is ticking, it is obvious that there is an urgency to address more collection and documentation especially on valuable and diverse species in Sarawak.

Assessing the conservation rank of a plant species is vital for effective conservation action to halt biodiversity loss and prevent future extinctions. Current global estimation specified that two out of five plant species are threatened with extinction by multiple risks, mainly due to the anthropogenic pressures, i.e. agriculture and aquaculture, biological resource use, natural system modifications, and residential and commercial development, plus the synergies among them that have had a major impact on biodiversity (IUCN Standards & Petitions Subcommittee, 2019; Antonelli et al., 2020). Unfortunately, the situation is currently happening in most parts of the state's forests, as well as in Peninsular Malaysia. Without ever being described, many plants have gone extinct; thus, continuous sampling and revelation of new species to science including wild gingers, that may potentially become a new source of medicine or global food source, is essential. Figure 1.1 illustrates the current situation of the forest cover loss in Borneo as adapted from Antonelli et al. (2020) and WWF (2020).

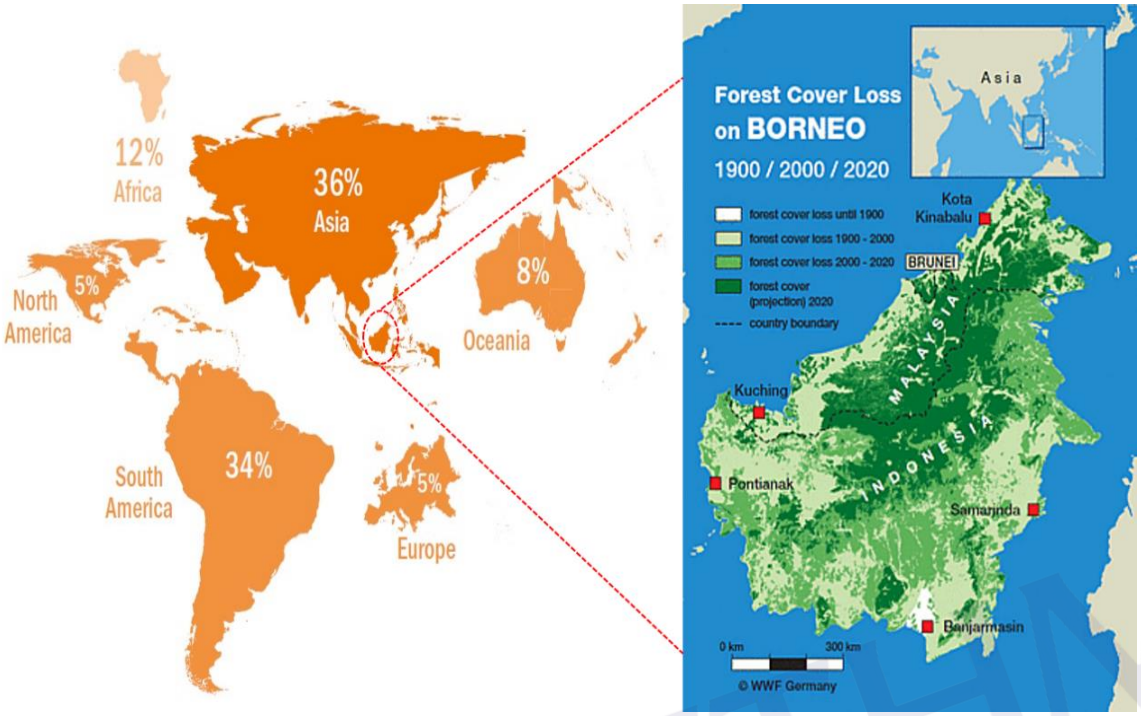


**Figure 1.1:** World map highlighting Asian region including Borneo recorded the highest number of newly described species in 2019 (Antonelli et al., 2020) and projection of the current forest cover loss in Borneo (WWF, 2020).

## 1.2 Problems Statement

Since the revisions of Bornean Zingiberaceae by R.M. Smith (1985, 1986a, 1986b, 1988, 1989), more botanical explorations have made additional collections of the Bornean species. Subsequent revisions by Sakai and Nagamasu (1998, 2000, 2003, 2006) in Lambir Hills NP recorded remarkably high number of Zingiberaceae species, i.e. 22 and 12 species from subfamilies Alpinioideae and Zingiberoideae, respectively. In contrast, very limited collections and species description have been made from the northeast area of Sarawak that includes the Bintulu district, since Beccari's time. Moreover, Similajau NP is the first totally protected area established in Bintulu district, but so far, records on its ginger flora are not available. In fact, several other TPAs in Sarawak are either lacking in available data on their ginger flora or in need of updating, such as Niah NP, which the only known record is from

Pearce in 2004, who concurrently reported on vegetation and plants in Niah NP. Hence, besides collating data on the current distribution of Alpinieae species in various localities in Sarawak, a comparative diversity study of the diversity in selected TPAs which represented different forests ecosystems, would be valuable especially for in-situ conservation efforts.

Apart from that, there are more recent additional documentations of gingers in Sabah and Sarawak which stipulated that the subfamily Alpinioideae encompasses the majority of ginger collections, surpassing other tribes in the family, which include the study by Gobilik et al. (2000) in Dagat Limestone Ridge, Gobilik and Mashitah (2005) in Trus Madi, Gobilik (2008) in Serudong, Ibrahim et al. (2010) in Lanjak Entimau, Gobilik and Limbawang (2010) in Tawau Hills Park, Julius et al. (2010) in Maliau Basin as well as Aimi Syazana et al. (2016) in Dered Krian National Park.

Owing to the fact that many species of gingers are native to and narrowly distributed in Sarawak, not only in the northern east but also the southern and western part, basic fieldworks and reassessment to obtain more accurate information and collections are required. Following more botanical collection, undoubtedly, an increasing number of taxa are expected to be recorded in Sarawak. This would also necessitate the study of their habitats, threats, and conservation measures as these are important information to assess the conservation status. Hence, it is imperative to evaluate their ecological parameters including the population size, area of occupancy, distribution, diversity, and richness at each habitat. Correspondingly, comparative diversity study on areas with different vegetation, i.e. mixed dipterocarp forest, coastal forest, and limestone forest from the whole of Sarawak is very scarce, though imperative as a stimulus for future in-situ conservation planning.

## REFERENCES


Acero, K. M. L., Amoroso, V. B., Lumista, H. P., Mendez, N. P., & Acma, F. M. (2019). Species composition and distribution of Zingiberaceae in Mt. Hamiguitan Expansion Site, Davao Oriental, Philippines. *Journal of Tropical Biology and Conservation*, *16*, 121–136.

Acma, F., & Mendez, N. P. (2018). Pollen morphology and pollen elemental composition of selected Philippine native gingers in tribe Alpinieae (Alpinioideae: Zingiberaceae). *Biological Forum*, *10*(1), 1–10.

Adams, R. P. (2017). *Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry* (4.1 ed.). Allured Publishing.

Aimi Syazana, S., Meekiong, K., Afifah, N., & Syauqina, M. Y. (2018). *Amomum bungoense*: a new species of *Amomum* (Zingiberaceae) from Sarawak, Malaysia. *Journal of Botany*, *2018*, 1–6.

Aimi Syazana, S., Meekiong, K., Rohaiza, D., Syauqina, M. Y., & Miraadila, M. I. (2016). *Comparison study on diversity of gingers (Zingiberaceae) from two limestone hills in the North Western of Sarawak* [Paper presentation]. Colloquium on Dered Krian National Park – Scientific Expedition 2016, Kuching, Sarawak, Malaysia.

Angela, G., Tawan, C. S., & Meekiong, K. (2014). Two new *Hornstedtia* species (Zingiberaceae) from Sarawak. *Folia Malaysiana*, *15*(1), 51–58.

Antonelli, A., Fry, C., Smith, R. J., Simmonds, M. S. J., Kersey, P. J., Pritchard, H. W., Abbo, M. S., Acedo, C., Adams, J., Ainsworth, A. M., Allkin, B., Annecke, W., Bachman, S. P., Bacon, K., Barrios, S., Barstow, C., Battison, A., Bell, E., Bensusan,

K., … Zhang, B. G. (2020). *State of the World's Plants and Fungi 2020*. Royal Botanic Gardens, Kew.

Baker, J. G. (1894). Scitamineae. In J. D. Hooker (Ed.), *Flora of British India Orchideae to Cyperaceae* (pp. 198–264). L. Reeve & Co.

Barra, A. (2010). Factors affecting chemical variability of essential oils: a review of recent developments. *Natural Product Communications*, *4*(8), 1147–1154.

Beentje, H. (2016). *Plant Glossary* (2nd ed.). Kew Publishing, Royal Botanical Gardens Kew.

BHL. (2020). *Biodiversity Heritage Library*. BHL Consortium. https://www.biodiversitylibrary.org/.

Bird, M. I., Taylor, D., & Hunt, C. (2005). Palaeoenvironments of insular Southeast Asia during the Last Glacial Period: a savanna corridor in Sundaland?. *Quaternary Science Reviews*, *24*, 2228–2234.

Bohlmann, J., Meyer-Gauen, G., & Croteau, R. (1998). Plant terpenoid synthases: molecular biology and phylogenetic analysis. *Proceedings of the National Academy of Sciences of the United States of America, 95*, 4126–4133.

Burkill, I. H., & Haniff, M. (1930). Malay village medicine. *The Gardens' Bulletin Straits Settlements, VI*, 256–260.

Burtt, B. L., & Smith, R. M. (1972). Tentative keys to the subfamilies, tribes and genera of the Zingiberales. *Notes from the Royal Botanic Garden, Edinburgh, 31*, 171–176.

Cámara-Leret, R., Frodin, D. G., Adema, F., Anderson, C., Appelhans, M. S., Argent, G., Guerrero, S. A., Ashton, P., Baker, W. J., Barfod, A. S., Barrington, D., Borosova, R., Bramley, G. L. C., Briggs, M., Buerki, S., Cahen, D., Callmander, M. W., Cheek, M., Chen, C. W., … van Welzen, P. C. (2020). New Guinea has the world's richest island

flora. *Nature, 5 Aug*, 1–16.

Chen, J., & Xia, N. H. (2011). Pollen morphology of Chinese *Curcuma* L. and *Boesenbergia* Kuntz (Zingiberaceae): taxonomic implications. *Flora*, *206*, 458–467.

Cowley, J. (1999). Two new species of *Plagiostachys* (Zingiberaceae) from Borneo. *Kew Bulletin, 54*(1), 139–146.

Cutler, D. F., Botha, T., & Stevenson, D. W. M. (2008). *Plant anatomy: an applied approach.* Blackwell Publishing Ltd.

Dahlgren, R., & Ramussen, F. N. (1983). Monocotyledon evolution: characters and phylogenetic estimation. *Evolution Biology*, *16*, 255–395.

Dahlgren, R. M. T., Clifford, H. T., & Yeo, P. F. (1985). *The Families of Monocolyledons*. Springer-Verlag.

Dan, M., Sabulal, M., George, V., & Pushpangadan, P. (2007). Studies on the rhizome oils from four *Hedychium* species of South India: a chemotaxonomic approach. *Gardens' Bulletin Singapore, 59*(1&2), 57–64.

de Albuquerque, E. S. B., Braga, J. M. A., & Vieira, R. C. (2013). Morphological characterisation of silica phytoliths in Neotropical Marantaceae leaves. *Plant Systematics Evolution*, *299*(9), 1–12.

De Boer, H., Newman, M., Poulsen, A. D., Droop, A. J., Tomáš, F., Thu Hiền, T., Hlavatá, K., Lamxay, V., Richardson, J. E., Steffen, K., & Leong-Škorničková, J. (2018). Convergent morphology in Alpinieae (Zingiberaceae): recircumscribing *Amomum* as a monophyletic genus. *TAXON*, *67*(1), 6–36.

Droop, A. J., & Newman, F. (2014). A revision of *Amomum* (Zingiberaceae) in Sumatra. *Edinburgh Journal of Botany, 71*(2), 193–258.

Erdtman, G. (1969). *Pollen Morphology and Plant Taxonomy: Angiosperms (an*

*Introduction to Palynology I).* Heffner Publishing.

Fitriady, M. A., Sulaswatty, A., Agustian, E., Salahuddin, & Aditama, D. P. F. (2017). Steam distillation extraction of ginger essential oil: study of the effect of steam flow rate and time process. *American Institute of Physics Conference Proceeding*, *1803*, 1–10.

Forest Department Sarawak. (2020). *Current status of constitution and conservation.* https://forestry.sarawak.gov.my/page-0-0-1239-Constitution-of-Permanent-Forests-A-Brief-History.html.

Furness, C. A., & Rudall, P. J. (1999). Inaperturate pollen in monocotyledons. *International Journal of Plant Sciences*, *160*, 395–414.

Gobilik, J. (2008). Diversity of gingers at Serudong, Sabah, Malaysia. *Journal of Tropical Biology and Conservation*, *4*(1), 15–21.

Gobilik, J., & Limbawang, S. (2010). Notes on species compisition and ornamental gingers in Tawau Hills Park, Sabah. *Journal of Tropical Biology and Conservation*, *7*, 31–48.

Gobilik, J., & Mashitah, Y. (2005). Zingiberaceae and Costaceae of the Trus Madi Range. *Journal of Tropical Biology and Conservation*, *1*, 79–93.

Gobilik, J., Magintan, D., Poulsen, A. D., & Mashitah, Y. (2000). *Gingers at the Dagat Limestone Ridge, Tabin Wildlife Reserve* [Paper presentation]. Seminar on Tabin Limestone Scientific Expedition, Kota Kinabalu, Sabah, Malaysia.

Gower, J. C. (1966). Some distance properties of latent toot and vector methods used in multivariate analysis. *Biometrika*, *53*, 325–338.

Grayum, M. H. (1986). Correlations between pollination biology and pollen morphology in the Araceae, with some implications for angiosperm evolution. In S. Blackmore & I. K. Ferguson (Eds.), *Pollen and spores: form and function* (pp. 313–327). Academic Press.

Grayum, M. H. (1990). Evolution and phylogeny of the Araceae. *Annals of the Missouri*

*Botanical Garden*, *77*, 628–697.

Harborne, J. B. (1973). *Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis.* Chapman and Hall Ltd.

Heather, A. C., & Perry, C. C. (2007). Silica in plants: biological, biochemical and chemical studies. *Annals of Botany*, *100*(7), 1383–1389.

Holttum, R. E. (1950). The Zingiberaceae of the Malay Peninsula. *Gardens' Bulletin Singapore*, *13*, 1–249.

Hussin, K. H., & Ibrahim, H. (1989). Taxonomic implications of several *Zingiber* species (Zingiberaceae) based on morphological and anatomical characteristics. *Malaysian Applied Biology*, *18*(2), 155–161.

Hussin, K., Ibrahim, H., Aminah, D., & Ali, H. (2001). Anatomical variations in leaf of *Boesenbergia* O. Kuntze and *Kaempferia* L. species (Zingiberaceae). *Journal of Tropical and Subtropical Botany*, *9*(1), 49–54.

Hussin, M. D., & Widjaja, E. A. (1987). Bukti anatomi dalam taksonomi kerabat-kerabat *Zingiber zerumbet*. *Floribunda*, *1*(1), 1–4.

Ibrahim, H. (2006). Gingers. In E. Soepadmo (Ed.), *The Encyclopaedia of Malaysia: Plants* (pp. 62–63). Institut Penyelidikan Perhutanan Malaysia.

Ibrahim, H., Meekiong, K., Ipor, I., Tawan, C. S., Hidir, M., Norhati, M. R., Lam, N. F., Lim, C. K., & Ampeng, A. (2010). *Gingers of Lanjak Entimau Wildlife Sanctuary* [Paper presentation]. Seminar of Biodiversity of Eastern Lanjak Entimau Wildlife Sanctuary, Kuching, Sarawak, Malaysia.

IPNI. (2020). *International Plant Names Index.* The Royal Botanic Gardens, Kew, Harvard University Herbaria & Libraries, & Australian National Botanic Gardens. http://www.ipni.org.

IUCN Standards and Petitions Subcommittee. (2019). *Guidelines for using the IUCN Red List Categories and Criteria, Version 14*. Standards and Petitions Committee of the IUCN Species Survival Commission.

IUCN. (2020). *IUCN Red List Categories and Criteria Version 2020-2*. International Union for Conservation of Nature. https://www.iucnredlist.org/.

Jantan, I., Mohd Yassin, M. S., Chin, C. B., Chen, L. L., & Sim, N. L. (2003). Antifungal activity of the essential oils of nine Zingiberaceae species. *Pharmaceutical Biology*, *41*(5), 392–397.

Julius, A. (2006). *Systematic study on the genus Plagiostachys Ridl. (Alpinioideae: Zingiberaceae) of Borneo* [Unpublished master's thesis]. Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah.

Julius, A., Suleiman, M., & Takano, A. (2008). Preliminary molecular phylogeny of Bornean *Plagiostachys* (Zingiberaceae) based on DNS sequence data of internal transcribed spacer (ITS). *Journal of Tropical Biology & Conservation, 4*, 67–80.

Julius, A., Suleiman, M., & Takano, A. (2007). Five new species of *Plagiostachys* (Zingiberaceae) from Borneo. *Acta Phytotaxonomica et Geobotanica, 58*(1), 1–17.

Julius, A., Takano, A. Suleiman, M., & Tukin, W. F. (2010). Zingiberaceae of Maliau Basin, Sabah, Malaysia. *Journal of Tropical Biology and Conservation*, *6*, 1–20.

Kaewsri, W., & Paisooksantivatana, Y. (2007). Morphology and palynology of *Amomum* Roxb. in Thailand. *Gardens' Bulletin Singapore, 59*, 105–112.

Kajornjit, P., Saensouk, S., & Saensouk, P. (2018). Pollen morphology and leaf anatomy of genus *Globba* in Thailand. *Science Asia*, *44*, 146–161.

Khaw, S. H. (2001). The genus *Etlingera* (Zingiberaceae) in Peninsular Malaysia including a new species. *Gardens' Bulletin Singapore, 53*, 191–239.

Kress, W. J. (1990). The phylogeny and classification of the Zingiberales. *Annals of the Missouri Botanical Garden*, *77*, 698–721.

Kress, W. J. (1995). Phylogeny of the Zingiberaceae: morphology and molecules. In P. J. Rudall, P. J. Cribb, D. F. Cutler & C. J. Humpries (Eds.), *Monocotyledons: Systematics and Evolution* (pp. 443–460). Kew Publishing, Royal Botanic Gardens, Kew.

Kress, W. J., Liu, A. Z., Newman, M., & Li, Q. J. (2005). The molecular phylogeny of *Alpinia* (Zingiberaceae): a complex and polyphyletic genus of gingers. *American Journal of Botany*, *92*(1), 167–178.

Kress, W. J., Newman, M. F., Poulsen, A. D., & Specht, C. (2007). An analysis of generic circumscriptions in tribe Alpinieae (Alpinioideae: Zingiberaceae). *Gardens' Bulletin Singapore*, *59*(1&2), 113–128.

Kress, W. J., Prince, L. M., & Williams, K. J. (2002). The phylogeny and a new classification of the gingers (Zingiberaceae): evidence from molecular and morphological data. *American Journal of Botany*, *89*, 1682–1696.

Lam, N. F., Ibrahim, H., Norhati, M. R., Meekiong, K., & Ipor, I. (2010). *Diversity analysis of selected Zingiberaceae species in Lanjak Entimau Wildlife Sanctuary* [Paper presentation]. Seminar of Biodiversity of Eastern Lanjak Entimau Wildlife Sanctuary, Kuching, Sarawak, Malaysia.

Lamb, A., Gobilik, J., Ardiyani, M., & Poulsen, A. D. (2013). *A Guide to Gingers of Borneo.* Natural History Publications (Borneo).

Larsen, K., Ibrahim, H., Khaw, S. H., & Saw, L. G. (1999). *Gingers of Peninsular Malaysia and Singapore*. Natural History Publications (Borneo).

Larsen, K., Lock, J. M., Maas, H., & Maas, P. J. M. (1998). Zingiberaceae. In K. Kubitzki (Ed.), *Flowering Plants: Monocotyledons* (pp. 474–495). Springer-Verlag.

Lim, C. K. (2001). Taxonomic notes on *Etlingera* Giseke (Zingiberaceae) in Peninsular Malaysia: the '*Achasma*' taxa, and supplementary notes on the '*Nicolaia*' taxa. *Folia Malaysiana*, *2*, 141–178.

Lim, C. K. (2003). Taxonomic notes on *Elettariopsis* Baker, and new taxa from Peninsular Malaysia & Thailand. *Folia Malaysiana*, *4*(3&4), 205–226.

Lumaga, M. R., Cozzolino, S., & Kocyan, A. (2006). Exine micromorphology of Orchidinae (Orchidoideae, Orchidaceae): phylogenetic constraints or ecological influences?. *Annals of Botany*, *98*, 237–244.

Magurran, A. E. (2004). *Measuring Biological Diversity*. Blackwell Publishing.

Mangaly, J. K., & Nayar, J. (1990). Palynology of South Indian Zingiberaceae. *Botanical Journal of the Linnean Society*, *103*, 351–366.

Meekiong, K., Ipor, I., Tawan, C. S., Ibrahim, H., Norhati, M. R., Lim, C. K., & Ampeng, A. (2011). Five new ginger species (Zingiberaceae) from the eastern part of Lanjak Entimau Wildlife Sanctuary, Sarawak, Borneo. *Folia Malaysiana*, *12*(1), 9–26.

Merrill, E. D. (1950). A brief survey of the present status of Bornean botany. *Webbia*, 309–324.

Metcalfe, C. R. (1963). *Comparative anatomy as a modern botanical discipline*. Clarendon Press.

Moles, T., Laffan, S. W., Keighery, M., Dalrymple, R. L., Tindall, M. L., & Chen, S. C. (2020). A hairy situation: plant species in warm, sunny places are more likely to have pubescent leaves. *Journal of Biogeography*, *10*, 1–11.

Neumann, K., Strömberg, C. A. E., Ball, T., Albert, R. M., Vrydaghs, L., & Cummings, L. S. (2019). International code for phytolith nomenclature (ICPN) 2.0. *Annals of Botany*, *XX*, 1–11.

Newman, M. F. (2020). *Zingiberaceae Resource Centre*. Royal Botanic Garden Edinburgh. https://padme.rbge.org.uk/ZRC/welcome.

Newman, M., Lhuillier, A., & Poulsen, A. D. (2004). Checklist of the Zingiberaceae of Malesia. *Blumea, 16*, 126–129.

Nonkratok, A., Saensouk, P., Saensouk, S., & Maknoi, C. (2012). Leaf surface anatomy of *Curcuma* L. in Northeastern Thailand. *KKU Research Journal*, *17*(3), 443–458.

Nur Anwariah, M., Assim, Z., Fasihuddin, B. A., & Meekiong, K. (2011, April 19–20). *Chemotaxonomic investigation of essential oil compounds in three species of Etlingera* [Paper presentation]. Taxonomist and Ecologist Conference 2011, Kuching, Sarawak, Malaysia.

Padalia, R., Verma, R. S., Sundaresan, V., & Chanotiya, C. S. (2010). Chemical diversity in the genus *Alpinia* (Zingiberaceae): comparative composition of four *Alpinia* species grown in Northern India. *Chemisty and Biodiversity*, *7*, 2076–2087.

Pearce, K. G. (2004). The vegetation and plants of Niah National Park, Borneo. *Gardens' Bulletin Singapore*, *56*, 101–145.

Pedersen, L. B. (2004). Phylogenetic analysis of the subfamily Alpinioideae (Zingiberaceae) with special emphasis on *Etlingera* Giseke, based on nuclear and plasmid DNA. *Plant Systematics and Evolution*, *245*, 239–258.

Piperno, D. R. (2006). *Phytoliths: a comprehensive guide for archaeologists and paleoecologists.* AltaMira Press.

Poulsen, A. D., Geri, C., Meekiong, K., & Roos, M. (2004). Zingiberaceae and Marantaceae. *The Sarawak Museum Journal Special Issue*, *6*, 163–169.

Poulsen, A. D. (2006). *Etlingera of Borneo*. Natural History Publications (Borneo).

Poulsen, A. D. (2007). *Etlingera* of Java. *Gardens' Bulletin Singapore, 59*(1&2), 145–172.

Poulsen, A. D., & Christensen, H. (2005). *Etlingera kenyalang* (Zingiberaceae) – a new species from Sarawak, Borneo, with notes on its ecology and Iban ethnobotany. *Nordic Journal of Botany*, *23*(4), 407–413.

Poulsen, A. D., Ardiyani, M., & Kusuma, W. C. (2009). *Etlingera loerzingii* (Zingiberaceae) – a gorgeous torch ginger from Sumatra grown in *Botanic gardens. Buletin Kebun Raya Indonesia*, *12*(1), 5–10.

Poulsen, A. D., Mathisen, H. B., Newman, M. F., Ardiyani, M., Lofthus, Ø., & Bjorå, C. S. (2018). *Sulettaria*: a new ginger genus disjunct from *Elettaria cardamomum. TAXON*. *67*(4), 725–738.

Poulsen, A. D., Mood, J., & Ibrahim, H. (1999). Three new species of *Etlingera* (Zingiberaceae) from Borneo. *Nordic Journal of Botany*, *19*, 139–147.

POWO. (2020). *Plants of the World Online*. Board of Trustees of the Royal Botanic Gardens, Kew. http://www.plantsoftheworldonline.org/.

Prychid, C. J., & Rudall, P. J. (1999). Calcium oxalate crystals in monocotyledons: a review of their structure and systematics. *Annals of Botany*, *84*, 725–739.

Prychid, C. J., Rudall, P. J., & Gregory, M. (2004). Systematics and biology of silica bodies in monocotyledons. *The Botanical Review*, *69*(4), 377–440.

Punt, W., Hoen, P. P., Blackmore, S., Nilsson, S., & Le Thomas, A. (2007) Glossary of pollen and spore terminology. *Review of Palaeobotany and Palynology, 143*, 1–81.

Puspitaningrum, D., Mustaqim, W. A., & Ardiyani, M. (2017). A new record of *Etlingera pauciflora* (Zingiberaceae) in Java, Indonesia. *Reinwardtia, 16*(1), 1–4.

Rangsiruji, A., Newman, M. F., & Cronk, Q. C. B. (2000a). Origin and relationships of *Alpinia galanga* (Zingiberaceae) based on molecular data. *Edinburgh Journal of Botany, 57*, 9–37.

Rangsiruji, A., Newman, M. F., & Cronk, Q. C. B. (2000b). A study of the infrageneric classification of *Alpinia* (Zingiberaceae) based on the ITS region of nuclear *rDNA* and the *trnL-F* spacer of chloroplast DNA. In K. L. Wilson & D. A. Morrison (Eds.), *Monocots—systematics and evolution* (pp. 695–709). CSIRO Publishing.

Ridley, H. N. (1899). The Scitamineae of the Malay Peninsula. *Journal of the Straits Branch of the Royal Asiatic Society, 32*, 85–184.

Ridley, H. N. (1909). Scitamineae of Borneo. *Journal of the Straits Branch of the Royal Asiatic Society, 46*, 229–246.

Rohlf, F. J. (1972). An empirical comparison of three ordination techniques in numerical taxonomy. *Systematic Zoology, 21*, 271–280.

Sabu, M., Sanoj, E., & Prasanth Kumar, M. G. (2008). *Plagiostachys nicobarica* (Zingiberaceae), new generic record and a new species from The Nicobar Islands, India. *Blumea, 53*, 329–334.

Saensouk, P., Chahtaranothai, P., & Theerakulpisut, P. (2009). Pollen morphology of the genus *Cornukaempferia* (Zingiberaceae) in Thailand. *Journal of Systematic and Evolution, 47*, 139–143.

Saensouk, P., Theerakulpisut, P., Thammathaworn, A., Saensouk, S., Maknoi, C., & Kohkaew, P. (2015). Pollen morphology of the genus *Curcuma* (Zingiberaceae) in Northeastern Thailand. *Science Asia, 41*, 87–92.

Sakai, S., & Nagamasu, H. (1998). Systematic studies of Bornean Zingiberaceae I. *Amomum* in Lambir Hill. *Edinburgh Journal of Botany, 55*, 45–64.

Sakai, S., & Nagamasu, H. (2001). Systematic studies of Bornean Zingiberaceae II. *Elettaria* in Lambir Hills. *Edinburgh Journal of Botany, 57*, 245–255.

Sakai, S., & Nagamasu, H. (2003). Systematic studies of Bornean Zingiberaceae IV.

Alpinioideae of Lambir Hill. *Edinburgh Journal of Botany*, *60*(2), 181–216.

Sakai, S., Kato, M., & Inoue, T. (1999). Three pollination guilds and variation in floral characteristics of Bornean gingers (Zingiberaceae and Costaceae). *American Journal of Botany*, *86*, 646–658.

Salasiah, M., & Meekiong, K. (2018). Preliminary anatomical study on leaf surfaces of Bornean Zingiberaceae (Tribe Alpinieae) from North East Sarawak. *Malaysian Applied Biology*, *47*(5), 289–293.

Salasiah, M., & Meekiong, K. (2020). *Plagiostachys strobilifera* var. *conica* (Zingiberaceae), a new variety from Sarawak, Borneo. *Reinwardtia*, *19*(2), 109–116.

Salasiah, M., Meekiong, K., & Poulsen, A. D. (2020). A new species and a new combination of *Sundamomum* (Zingiberaceae) from Sarawak, Borneo. *Kew Bulletin, 70*(58), 1–6.

Sandasi, M., Kamatou, G. P. P., Combrinck, S., & Viljoen, A. M. (2013). A chemotaxonomic assessment of four indigenous South African *Lippia* species using GC-MS and vibrational spectroscopy of the essential oils. *Biochemical Systematics and Ecology*, *51*, 142–152.

Sannier, J., Baker, W. J., Anstett, M-C., & Nadot, S. (2009). A comparative analysis of pollinator type and pollen ornamentation in the Araceae and the Arecaceae, two unrelated families of the monocots. *BMC Research Notes*, *2*(145), 1–11.

Saw, L. G., & Chung, R. C. K. (2015). The flora of Malaysia projects. *Rodriguésia*, *66*(4), 947–960.

Schumann, K. M. (1904). Zingiberaceae. In A. Eangler (Ed.), *Das Pflanzenreich* (pp. 1–458). Wilhelni Engelniann.

Setyawan, A. D. (2002). Chemotaxonomic studies on the genus *Amomum* based on chemical components of volatile oils. *Hayati*, *9*, 71–79.

Singh, G., Kapoor, I. P. S., Singh, P., Heluani, G. S. D., & Lampasona, M. P. D. (2008). Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of *Zingiber officinale*. *Journal of Food and Chemical Toxicology, 46*, 3295–3302.

Smith, R. M. (1984). Zingiberaceae of Gunung Mulu National Park. In A. C. Jermy (Ed.), *Studies on the Flora of Gunung Mulu National Park Sarawak*. Forest Department Sarawak.

Smith, R. M. (1982). Systematic notes on a new species of Zingibereaceae of the Gn. Mulu National Park. *Botanical Journal of the Linnean Society, 85*, 36–73.

Smith, R. M. (1985). A review of Bornean Zingiberaceae: I (Alpinieae). *Notes from the Royal Botanic Garden, Edinburgh*, *42*, 261–314.

Smith, R. M. (1986a). A review of Bornean Zingiberaceae II: (Alpinieae, concluded). *Notes from the Royal Botanic Garden, Edinburgh*, *43*, 439–466.

Smith, R. M. (1986b). New combinations in Etlingera Giseke (Zingiberaceae). *Notes from the Royal Botanic Garden, Edinburgh*, *43*, 243–254.

Smith, R. M. (1988). A review of Bornean Zingiberaceae: IV (Globbeae). *Notes from the Royal Botanic Garden, Edinburgh*, *45*, 1–19.

Smith, R. M. (1989). A review of Bornean Zingiberaceae: V (*Zingiber*). *Notes from the Royal Botanic Garden, Edinburgh*, *45*, 409–423.

Smith, R. M. (1990). *Alpinia* (Zingiberaceae): a proposed new infrageneric classification. *Edinburgh Journal of Botany*, *47*, 1–75.

Sokal, R. R. (1986). Phenetic taxonomy: theory and methods. *Annual Review of Ecology, Evolution, and Systematics*, *17*, 423–442.

Sorrels, L., & Glenn, S. (1991). Review of sampling techniques used in studies of grassland plant communities. *Proceedings of the Oklahoma Academy of Science, 71*, 43–45.

Strömberg, C. A. E., Di Stilio, V. S., & Song, Z. (2016). Functions of phytoliths in vascular plants: an evolutionary perspective. *Functional Ecology*, *30*, 1286–1297.

Stuessy, T. F. (1990). *Plant Taxonomy: The Systematic Evaluation of Comparative Data*. Columbia University Press.

Takano, A., Mashitah, M. Y., & Gisil, J. (2004). *The Zingiberaceae of Crocker Range Park: a preliminary survey, checklist and generic key* [Paper presentation]. Crocker Range Scientific Expedition 2002 Seminar. Kota Kinabalu, Sabah, Malaysia.

Talip, N., Hussin, K. H., & Ibrahim, H. (2005). Comparactive leaf anatomy of *Alpinia* species (Zingiberaceae) in Malaysia. *Nordic Journal of Botany*, *23*, 463–483.

Theanphong, O., Jenjittikul, T., & Mingvanish, W. (2016). Chemotaxonomic study of volatile oils from rhizomes of nine *Zingiber* species (Zingiberaceae). *Thai Journal of Botany*, *8*(1), 127–139.

Theilade, I., Mærsk-Møller, M. L., Theilade, J., & Larsen, K. (1993). Pollen morphology and structure of *Zingiber* (Zingiberaceae). *Grana*, *32*(6), 338–342.

Tomlinson, P. B. (1956). Studies in the systematic anatomy of the Zingiberaceae. *Botanical Journal of the Linnean Society*, *55*, 547–592.

Tomlinson, P. B. (1960). Commelinales, Zingiberales. In C. R. Metcalfe (Ed.), *Anatomy of the Monocotyledons* (pp. 341–359). Clarendon Press.

Tomlinson, P. B. (1962). Phylogeny of the Scitamineae-morphological and anatomical considerations. *Evolution*, *16*, 192–213.

Uno, G., Sporne, K., & Endres, P. (2001). Some observations on the evolution of pollen types in dicotyledons. *New Phytologist*, *71*(1), 181–185.

Valeton, T. (1913). Zingiberaceae. *Nova Guinea*, *8*, 923–988.

Van Den Dool, H., & Dec. Kratz, P. (1963). A generalization of the retention index system

including linear temperature programmed gas-liquid partition chromatography. *Journal of Chromatography*, *11*, 463–471.

Wang, L., Nie, Q., Li, M., Zhang, F., Zhuang, J., Yang, W., Li, T., & Wang, Y. (2005). Biosilicified structures for cooling plant leaves: a mechanism of highly efficient midinfrared thermal emission. *Applied Physics Letters*, *87*, 1–4.

Waterman, P. G. (2007). The current status of chemical systematics. *Phytochemistry*, *68*, 2896–2903.

Waterman, P. G., & Mole, S. (1989). Extrinsic factors influencing production of secondary metabolites in plants. In E. A. Bernays (Ed.), *Insect–Plant Interactions* (pp. 107–134). CRC Press.

WCVP. (2020). *World Checklist of Vascular Plants*, version 2.0. The Royal Botanic Gardens, Kew. https://wcvp.science.kew.org/

Williams, K. J., Kress, W. J., & Manos, P. S. (2004). The phylogeny, evolution, and classification of the genus *Globba* and tribe Globbeae (Zingiberaceae): appendages do matter. *American Journal of Botany*, *91*, 100–114.

Wong, K. M. (1995). A brief history of botanical collecting and documentation in Borneo. In E. Soepadmo & K. M. Wong (Eds.), *Tree Flora of Sabah and Sarawak* (pp. XXI-XXXVI). Forest Research Centre Kepong.

WWF. (2020). *The Heart of Borneo Under Siege*. World Wide Fund for Nature. https://wwf.panda.org/discover/knowledge_hub/where_we_work/borneo_forests/borneo_deforestation/?.

Xia, Y. M., Kress, W. J., & Prince, L. M. (2004). A phylogenetic analysis of *Amomum* (Alpinioideae: Zingiberaceae) using ITS and *mat*K DNA sequence data. *Systematic Botany*, *29*, 334–344.

Záveská, E., Fér, T., Šída, O., Marhold, K., & Leong-Škorničková, J. (2016). Hybridization among distantly related species: examples from the polyploid genus *Curcuma* (Zingiberaceae). *Molecular Phylogenetics and Evolution*, *100*, 303–321.

## **APPENDIX 3:** LIST OF PUBLICATIONS

1. **Salasiah, M.** & Meekiong, K. (2018). Preliminary anatomical study of leaf surfaces of Bornean Zingiberaceae (Tribe Alpinieae) from Northeast Sarawak. *Malaysian Applied Biology*, *47*(5), 289–293.
2. **Salasiah, M.** & Meekiong, K. (2019). Assessment of Zingiberaceae (Tribe Alpinieae) from Northeast Sarawak, Malaysia. *IOP Conference Series: Earth and Environmental Science*, *269*, 1–7. DOI: 10.1088/1755-1315/269/1/012032
3. **Salasiah, M.** & Meekiong, K. (2020). *Plagiostachys strobilifera* var. *conica (*Zingiberaceae), a new variety from Sarawak, Borneo. *Reinwardtia*, *19*(2), 109–116. DOI: 10.14203/reinwardtia.v19i2.3861
4. **Salasiah, M.**, Meekiong, K. & A. D. Poulsen. (2020). A new species and a new combination of *Sundamomum* (Zingiberaceae) from Sarawak, Borneo. *Kew Bulletin*, *70*(58), 1–6. DOI: 10.1007/s12225-020-09919-y