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Lichen diversity and taxonomy in Bukit Barisan Grand Forest Park, North Sumatra, Indonesia

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Abstract. *Atni OK, Munir E, Siregar ES, Saleh MN. 2024. Lichen diversity and taxonomy in Bukit Barisan Grand Forest Park, North Sumatra, Indonesia. Biodiversitas 25: 1623-1630.* Located in Bandar Baru Village, Deli Serdang District, North Sumatra, Bukit Barisan Grand Forest Park stands out for its uniqueness and high biodiversity, including lichens. This study aims to identify and map lichen diversity in the research area. Surveys were conducted from January to February 2024 using an exploratory method along designated tracks. Therefore, 57 lichen species from 23 families and 38 genera were found. Based on their thallus types, 26 lichen species were identified as crustose, 17 as foliose, 6 as squamulose, 5 as fruticose, and 3 as filamentous. Reproductive structures varied, 13 species possessed apothecia, soredia, and lacked distinguishable reproductive structures, 10 had lirellae, 7 had perithecia, and 2 had isidia. Graphidaceae emerged as the most prevalent family with 8 species, predominantly growing on bark substrates. Although lichen distribution correlated with pH levels, its correlation with the preference for lower pH levels was low. Host trees from the Pinaceae and Lauraceae families were the most populated by lichens in this study. Research on lichen diversity in Bukit Barisan Grand Forest Park is crucial, considering the increasing development and deforestation in North Sumatra. A more comprehensive study of lichens is urgently required.

Keywords: Diversity, lichen, taxonomy

INTRODUCTION

Forests serve as a habitat for the growth of lichens; Bukit Barisan Grand Forest Park, Bandar Baru Village, boasts an exceptionally high biodiversity, with lichens being one of the most diverse groups in this forest. Lichens form living communities through by interacting with specific fungi with small algae or bacteria, creating an environment that supports other microorganisms (Hawksworth and Grube 2020). The main characteristics of lichens are commonly understood to be primarily shaped by the dominant type of fungus, known as the mycobiont (Honegger 2012; Hawksworth and Grube 2020). Meanwhile, the algae or bacteria involved in photosynthesis within lichens can be single-celled green algae or blue-green cyanobacteria, termed chlorobionts or cyanobionts, respectively (Paul et al. 2018). This strong symbiotic relationship between fungi and their photosynthetic partners represents one of the most effective means of acquiring nutrients for fungi. It occurs across almost every terrestrial environment on Earth (Lücking et al. 2016). In the natural environment, fungi rely on specific types of algae to thrive, indicating their dependence on these organisms for survival and the formation of lichens (Spribille et al. 2022). Lichens, which grow as epiphytes on trees, rocks, and various substrates, exhibit resilience to water scarcity and do not require complex living conditions (Elkhateeb et al. 2022). Their widespread distribution from coastal areas to mountainous regions in Indonesia highlights their adaptability and ability to inhabit diverse ecological niches (Vondrák et al. 2022).

Lichens are robust organisms that thrive in various environments, and factors such as humidity, temperature, air quality, and nutrient availability influence their populations (Baldauf et al. 2021; Geiser et al. 2021; Stanton et al. 2023). Lichens have diverse uses, including dye production and medical applications, and exhibit pharmacological activities such as antibacterial, antifungal, antitumor, and antioxidant properties (Kalra et al. 2020; Elkhateeb et al. 2021; Elkhateeb et al. 2022). Lichens have the potential to be utilized as a natural reservoir for discovering novel active compounds, whether through modifying compounds isolated from natural sources or via their secondary metabolites (Ren et al. 2023). Lichens produce a wide array of secondary metabolite classes, including derivatives of amino acids, pulvinic acid, peptides, sugar alcohols, terpenoids, steroids, carotenoids, aliphatic acids, monohydroxy phenols, depsides, dibenzofurans, anthraquinones, xanthones, usnic acid, among others (Millot et al. 2016; Tatipamula and Tatipamula 2021; Macedo et al. 2021; Goga et al. 2020; Badiali et al. 2023). In addition, lichens can serve as bioindicators of air quality, climate change, and regional biodiversity, with their use as such being more cost-effective and efficient than ambient indicator devices or machines (Aptroot et al. 2021). Comprehensive research on the functional traits and potential uses of lichens is crucial to understand the ecosystem services they provide and their benefits to humans. Such research requires surveys of diverse species that are abundant or unique to a particular area.

The variety and spread of lichen species are affected by various geographic factors such as latitudinal and altitudinal variations, environmental conditions, and microenvironments. (Abas and Din 2021). Despite a heightened focus on temperate and boreal habitats, the reasons behind the high biodiversity of lichens in tropical regions remain unclear. Indonesia boasts abundant biodiversity; however, studies on lichen diversity are lacking, particularly in North Sumatra. Existing research on lichens in this region, such as those by Khairunnisa (16 species) in 2016, Hutasuhut (19 species) in 2021, and Pasaribu (54 species) in 2023, underscores the critical importance of exploring the richness of lichen species. With the escalating rates of development and deforestation across various parts of North Sumatra, there is an urgent need for more extensive research on lichens. Such endeavors not only shed light on the functional characteristics of lichens and their ecological contributions but also hold potential benefits for humans.

MATERIALS AND METHODS

Study area

The study was conducted between January and February 2024 within the Bukit Barisan Grand Forest Park, Bandar Baru Village, Sibolangit District, Deli Serdang District, North Sumatra, Indonesia (Figure 1). This nature reserve spans an extensive area of 51,600 hectares, with an altitude range from 864 to 1,192 masl. The Sibolangit District experiences a notably high average annual rainfall of 4,273.3 mm, with approximately 188 rainy days annually. Within the Bukit Barisan Nature Reserve area in Bandar Baru Village, the air temperature can rise to 22.4°C, accompanied by a humidity level of 87.1%. Lichen identification and subsequent data analysis were conducted at the Microbiology Laboratory under the Biology Study Program in the Faculty of Mathematics and Natural Sciences at Universitas Sumatera Utara.

Field method

Data collection and specimen processing

This study utilized an exploratory approach along Bukit Barisan Grand Forest Park, Bandar Baru Village trail. Observations and collections were conducted along these trails, with lichen samples obtained from substrates using a knife. Lichen samples growing on bark substrates were collected at a height of 2 m above ground level. The lichen species were photographed upon discovery and their key characteristics, such as thallus and organ reproduction, were documented on a tally sheet. Subsequently, the samples were carefully stored in labeled envelopes that provided detailed descriptions for identification purposes. Various physical parameters including altitude, air temperature, humidity, and light intensity, were quantified using an altimeter, thermometer, hygrometer, and lux meter.

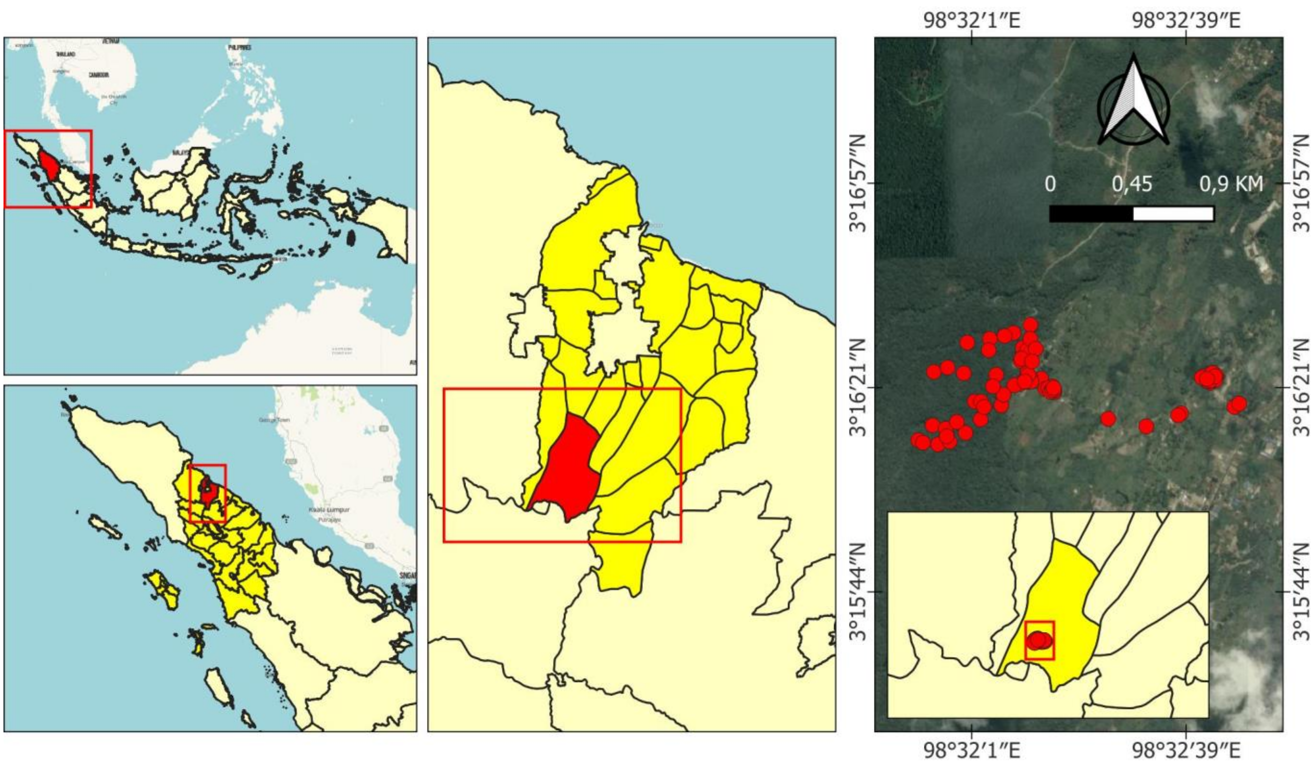


Figure 1. Map of lichen sampling point (*red dots*) in Bukit Barisan Grand Forest Park, Bandar Baru Village, Sibolangit Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

Following collection, the lichen specimens underwent a preservation process involving replacing the envelope paper and air-drying to prevent deterioration, moisture accumulation, and mold growth. The dried specimens were archived at the Microbiology Laboratory, Biology Study Program, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara. To measure the pH of the substrate, the bark or leaf samples were dried for a week at room temperature (25-30°C) in the laboratory. Bark pH was determined as recommended by Öztürk and Seyhan (2011). Any remnants of bryophytes and lichens were first removed from the tree bark to prevent their influence on the pH. Subsequently, 2 grams of bark from each tree was weighed, ground using a knife and muller, and suspended in 20 mL of distilled water. The suspensions were shaken for 1 hour and allowed to stand for 1 day. The supernatant was then filtered through filter paper into test tubes. Finally, the pH of the supernatant was measured using a pH meter and the correlation between pH and the lichen community was examined utilizing a linear regression model.

Lichen identification

Lichen identification involves several steps: (i) Determination of the growth forms, including foliose, squamulose, crustose, or fruticose, which are crucial for distinguishing genera; (ii) The presence of reproductive structures such as soredia, isidia, perithecia, apothecia, and lirellae, crucial for identifying lichens at the species level, was examined in the laboratory using a hand lens and CX43 Biological Microscope. Observations of the cilia and the condition of the lower side were also noted; (iii) Chemical tests, including color and crystal tests, were performed by applying different reagents, specifically calcium hypochlorite, potassium hydroxide, and KC reagent, to the thallus surface or exposed medulla and observing rapid color changes, typically red or yellow, to determine the species. The identification process was guided by reference books such as Brodo (2016), Thomson (2019), and Muvidha (2020), and checklist journals from tropical areas such as (Weerakoon and Aptroot 2004; Schumm and Aptroot 2012; Buaruang et al. 2017) using identification keys. Cross-sectional cuts of the thallus were placed on slides, and reagents were dripped onto the sample while observing color changes in the medulla under a microscope. It is important to note that not all lichen species react to all spot tests, and multiple tests may be required for definitive identification. Additionally, environmental conditions and sample age can influence spot test results. Therefore, a combination of morphological, chemical, and molecular methods is essential for accurate lichen identification.

RESULTS AND DISCUSSION

Lichen diversity

Research findings determined the presence of 57 lichen species, spanning 23 families and 38 genera, the distribution map of its species, as illustrated in Figure 1. The quantity of lichen species observed in this investigation surpasses that reported by Hutasuhut et al. (2021) in the Sicikeh-cike Dairi District, who documented 19 lichen species across 7 families, as well as Pasaribu et al. (2023), who recorded 54 lichen species across 23 families in the Batang Toru forest. Variations in the number of lichen species recorded across the study sites stemmed from differences in the research duration, sampling intensity, exploration area within the forest, and diverse environmental conditions aligning with the habitats favored by lichen species. Bukit Barisan Grand Forest Park, Bandar Baru Village, also exhibits environmental factors conducive to lichen growth, including air humidity ranging from 50 to 92%, air temperatures between 21 and 30°C, and a relatively high annual rainfall of approximately 4,273.3 mm, with an average of 188 rainy days per year. Temperature and relative humidity changes affect the lichens physiological response and survival, with air dryness considered to have a more substantial impact than temperature increase on lichen survival and distribution (Kubiak and Osyczka 2020). Rainfall affects lichen growth; however, the frequency of rainy days is a better predictor of growth than total rainfall or rainfall intensity alone. Specifically, lichen growth significantly increases with both the amount and frequency of precipitation, while the direct impact of rainfall on lichen growth remains minimal (Phinney et al. 2021). Bukit Barisan Grand Forest Park, Bandar Baru Village, also spans an elevation ranging from approximately 865 m to 978 masl. The altitude is an environmental factor influencing the number of lichens in the area. Elevation strongly correlates with lichen richness, predicting richer communities at higher elevations (Bässler et al. 2016).

The most commonly encountered lichen family is Graphidaceae, comprising 8 species of lichens. The Graphidaceae family is characterized by ascomata, elongated or branched structures that serve as sexual reproductive organs, known as lirellae. This family also exhibited a widespread distribution along the research track, with all Graphidaceae species found growing exclusively on tree bark. According to van den Boom et al. (2023), Graphidaceae is the largest crustose lichen family worldwide. Table 1 shows that 57 lichen species were recorded in the study area. Among these, 54 species thrived on bark substrates, including *Cryptothecia scripta*, *Coccocarpia palmicola*, *Coenogonium implexum*, *Pyrenula astroidea*, *Bacidia schweinitzii*, and *Pyxine cocoës*. Additionally, 3 species were found on the leaf substrates, *Cryptothecia effusa*, *Microtheliopsis uleana*, and *Chroodiscus argillaceus*. Two species inhabited stone substrates, *Cladonia squamosa* and *Verrucaria muralis*, while *Stereocaulon graminosum* was observed on the soil substrate. Three lichen species *Cladonia squamosa*, *Stereocaulon graminosum*, and *Verrucaria muralis* are each found to inhabit two different substrates.

Table 1. Lichen distribution at Bukit Barisan Grand Forest Park, Bandar Baru Village, Deli Serdang District, North Sumatra, Indonesia

Families	Species	Sub-strates	Repro-duction	Thallus Type	Chemical spot test		
					K	C	KC
Arthoniaceae	*Cryptothecia effusa* (Müll. Arg.) R. Sant.	Leaf	Soredia	Crustose	+	-	+
	Cryptothecia scripta G. Thor	Bark	-	Crustose	+	-	+
	Cryptothecia striata G. Thor	Bark	Soredia	Crustose	+	-	+
Caliciaceae	*Dirinaria applanata* (Fée) D.D. Awasthi	Bark	Soredia	Foliose	+	-	+
	Pyxine cocoës (Sw.) Nyl.	Bark	Isidia	Foliose	-	+	-
Carbonicolaceae	*Carbonicola anthracophila* (Nyl.) Bendiksby & Timdal	Bark	Perithecia	Squamulose	-	-	-
Cladoniaceae	*Cladonia macrophylla* (Schaer.) Stenh.	Bark	Apothecia	Squamulose	+	-	-
	Cladonia squamosa (Scop.) Hoffm.	Rock, bark	Soredia	Squamulose	+	-	-
Coccocarpiaceae	*Coccocarpia erythroxyli* (Spreng.) Swinscow & Krog	Bark	Apothecia	Foliose	+	-	-
	Coccocarpia palmicola (Spreng.) Arv. & D.J. Galloway	Bark	Apothecia	Foliose	+	+	-
	Coccocarpia pellita (Ach.) Müll. Arg.	Bark	Apothecia	Foliose	+	+	-
Coenogoniaceae	*Coenogonium implexum* Nyl.	Bark	Apothecia	Filamentous	+	+	-
	Coenogonium interplexum Nyl.	Bark	Apothecia	Filamentous	+	-	-
	Coenogonium linkii Ehrenb.	Bark	-	Filamentous	+	-	-
Collemataceae	*Leptogium asiaticum* P.M. Jørg., Herzogia	Bark	Soredia	Foliose	+	-	-
Graphidaceae	*Chroodiscus argillaceus* (Müll. Arg.) Lücking & Papong	Leaf	Apothecia	Crustose	+	-	-
	Fissurina rufula (Mont.) Staiger	Bark	Lirellae	Crustose	-	-	+
	Glyphis cicatricosa Ach.	Bark	Lirellae	Crustose	+	+	-
	Graphis scripta (L.) Ach.	Bark	Lirellae	Crustose	+	-	+
	Pallidogramme chrysenteron (Mont.) Staiger, Kalb & Lücking	Bark	Lirellae	Crustose	+	-	-
	Platythecium floridanum (Tuck.) Lendemer	Bark	Lirellae	Crustose	+	-	+
	Sarcographa labyrinthica (Ach.) Müll. Arg.	Bark	Lirellae	Crustose	+	-	+
	Thecaria montagnei (Bosch) Staiger	Bark	Lirellae	Crustose	+	-	-
Haematommataceae	*Haematomma persoonii* (Fée) A. Massal.	Bark	Apothecia	Crustose	+	-	+
Lichenomphaliaceae	*Dictyonema thelephora* (Spreng.) Zahlbr.	Bark	Soredia	Foliose	+	-	-
Megalosporaceae	*Megalospora atrorubicans* (Nyl.) Zahlbr.	Bark	Perithecia	Crustose	+	+	+
Microtheliopsidaceae	*Microtheliopsis uleana* Müll. Arg.	Leaf	-	Crustose	-	+	-
Opegraphaceae	*Opegrapha herbarum* Mont., Arch. Bot. (Forlì)	Bark	Lirellae	Crustose	+	-	-
	Opegrapha viridis Eckfeldt	Bark	Lirellae	Crustose	+	-	-
Parmeliaceae	*Bulbothrix laevigatula* (Nyl.) Hale	Bark	Soredia	Foliose	+	+	+
	Parmotrema clavuliferum (Räsänen) Streimann	Bark	Apothecia, soredia	Foliose	+	+	+
	Parmotrema tinctorum (Despr. ex Nyl.) Hale	Bark	Soredia	Foliose	+	+	+
	Parmotrema xanthinum (Müll. Arg.) Hale	Bark	-	Foliose	+	+	+
	Relicina eximbricata (Gyeln.) Hale	Bark	Soredia	Foliose	+	-	+
	Usnea confusa Asahina	Bark	-	Fruticose	+	-	+
	Usnea sp 1.	Bark	-	Fruticose	+	-	-
	Usnea sp 2.	Bark	-	Fruticose	+	-	-
Peltigeraceae	*Sticta hypochra* Vain.	Bark	-	Foliose	+	-	+
	Sticta subcaperata (Nyl.) Nyl.	Bark	Apothecia	Foliose	+	-	+
Pertusariaceae	*Pertusaria tropica* Vain.	Bark	Soredia	Crustose	+	-	+
Phlyctidaceae	*Phlyctis himalayensis* (Nyl.) D.D. Awasthi	Bark	Apothecia	Crustose	+	-	-
Physciaceae	*Physcia undulata* Moberg	Bark	Soredia	Foliose	+	+	+
	Polyblastidium hypoleucum (Ach.) Kalb	Bark	-	Foliose	+	+	+
	Polyblastidium japonicum (M. Satô) Kalb	Bark	Apothecia	Foliose	+	+	+
Pyrenulaceae	*Pyrenula astroidea* (Fée) R.C. Harris	Bark	Perithecia	Crustose	+	-	+
	Pyrenula mamillana (Ach.) Trevis.	Bark	Perithecia	Crustose	+	-	+
	Pyrenula thelemorpha Tuck.	Bark	Perithecia	Crustose	+	-	+
Ramalinaceae	*Bacidia schweinitzii* (Tuck.) A. Schneid.	Bark	-	Squamulose	+	+	-
	Krogia borneensis Kistenich & Timdal	Bark	Soredia	Squamulose	+	-	+
	Phyllopsora furfuracea (Pers.) Zahlbr.	Bark	Isidia	Fruticose	+	-	-
Stereocaulaceae	*Stereocaulon graminosum* Schaer.	Soil, bark	-	Fruticose	+	+	+
Trypetheliaceae	*Trypethelium eluteriae* Spreng.	Bark	Lirellae	Crustose	+	+	+
	Trypethelium tropicum (Ach.) Müll. Arg.	Bark	Perithecia	Crustose	+	-	+
Verrucariaceae	*Agonimia tristicula* (Nyl.) Zahlbr.	Bark	-	Squamulose	+	-	-
	Verrucaria muralis Ach.	Rock, bark	Perithecia	Crustose	-	+	-
	Unidentified crustose lichen 1.	Bark	Apothecia	Crustose	+	-	-
	Unidentified crustose lichen 2.	Bark	-	Crustose	+	-	-

Note: K: KOH 10%, C: $Ca(OCl)_2$ 10%, KC: KOH 10% + $Ca(OCl)_2$ 10%

The presence of lichen species on bark substrates is significant, as McDonald et al. (2017) noted, and can be attributed to tree bark's favorable environment for their growth and development. Tree bark can retain moisture due to its porous texture, creating optimal conditions for lichens to attach and thrive. Moreover, tree bark offers protection against excessive sunlight exposure and dry winds, thereby preserving moisture and maintaining a stable microenvironment essential for lichen growth. Consequently, lichens are predominantly found on tree bark surfaces compared to other substrates that do not offer conducive conditions for their proliferation.

Lichen thallus

Lichens display a variety of thallus forms, including foliose, crustose, fruticose, squamulose, and filamentous (Figure 2). Within the study area, 26 species were classified as crustose lichens, including *Cryptothecia striata, Fissurina rufula, Trypethelium tropicum, Phlyctis himalayensis, Trypethelium eluteriae, Pyrenula thelemorpha, Haematomma persoonii,* and *Pertusaria tropica*. Seventeen species were categorized as foliose lichens, including *Pyxine cocoës, Coccocarpia erythroxyli, Leptogium asiaticum, Parmotrema clavuliferum, Sticta hypochra, Bulbothrix laevigatula,* and *Parmotrema xanthinum.* Six species were classified as squamulose lichens, namely *Carbonicola anthracophila, Cladonia squamosa, Cladonia macrophylla, Bacidia schweinitzii, Krogia borneensis,* and *Agonimia tristicula*. Five species were identified as fruticose lichens, including *Usnea confusa, Usnea* sp1., *Usnea* sp2., *Phyllopsora furfuracea,* and *Stereocaulon graminosum. Coenogonium implexum, Coenogonium interplexum,* and *Coenogonium linkii* were classified as filamentous lichens.

The predominant lichen thallus type among the various species was crustose with 46% variety of thallus, as shown in Figure 3. The crustose thallus resembles a shell, being firm and brick-like, and typically grows on tree trunks and dead wooden surfaces, often exhibiting a small scribble-like appearance. Removing this type of lichen without damaging the substrate can be challenging. According to Nascimbene and Marini (2015), crustose lichens demonstrate greater resilience to rising temperatures than foliose and fruticose-filamentose species. This resilience is attributed to their lower surface-to-volume ratio, meaning they have less exposed surface area, resulting in a higher tolerance to drying out. Water loss mainly occurred at the upper exposed surface.

Lichen reproduction structure

Lichen propagation occurs via two separate mechanisms: asexual and sexual reproduction. Asexual reproduction occurs when the lichen generates soredia and isidia on its thallus surface. Sexual reproduction entails the development of specialized fungal structures such as apothecia, perithecia, and lirellae. In this study, the recognized reproductive formations of lichens comprised the apothecia, perithecia, lirellae, soredia, and isidia (Figure 4).

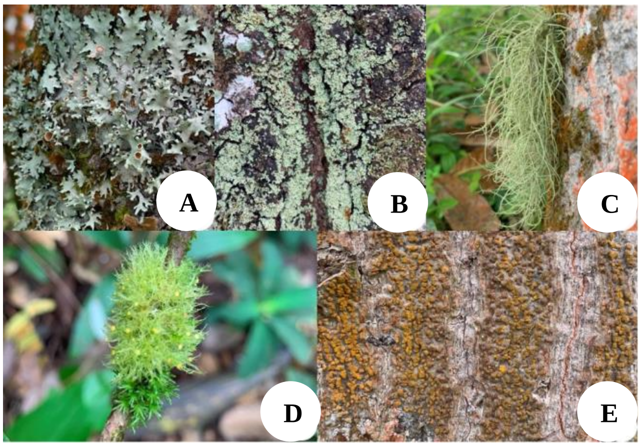


Figure 2. The shape of the lichen thalli: A. Foliose, *Parmelia clavuliferum*; B Squamulose, *Krogia borneensis*; C. Fruticose, *Usnea* Sp 2.; D. Filamentous, *Coenogonium interimplexum*; F. Crustose, *Trypethelium eluteriae*

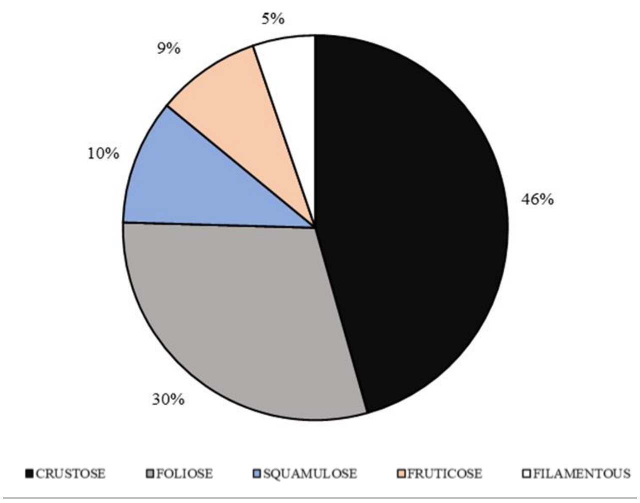


Figure 3. Percentage of lichen type of thallus across species

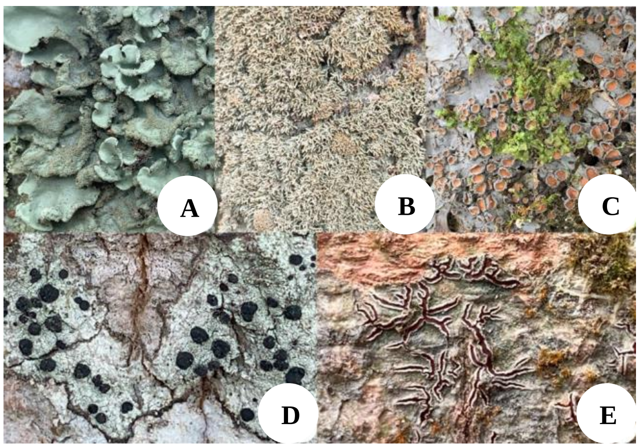


Figure 4. Lichen reproductive structures: A. Soredia in *Parmotrema tinctorum*; B. Isidia in *Phyllopsora furfuracea*; C. Apothecia on *Sticta subcaperata*; D. Perithecia on *Megalospora atrorubicans*; E. Lirellae on *Thecaria montagnei*

Thirteen species of lichens were identified with apothecia in this study, including *Coccocarpia pellita, Coenogonium implexum, Chroodiscus argillaceus, Sticta subcaperata, Haematomma persoonii,* and *Polyblastidium japonicum.* A further thirteen species were found to have soredia, such as *Dirinaria applanata, Cladonia squamosa, Leptogium asiaticum, Bulbothrix laevigatula, Relicina eximbricata, Parmotrema tinctorum, Physcia undulata,* and *Pertusaria tropica*. Ten species exhibited lirellae, including *Fissurina rufula, Pallidogramme chrysenteron, Sarcographa labyrinthica, Thecaria montagnei, Glyphis cicatricosa, Graphis scripta,* and *Trypethelium eluteriae*. Seven lichen species were observed with perithecia, such as *Megalospora atrorubicans, Trypethelium tropicum, Pyrenula thelemorpha,* and *Pyrenula mamillana*. *Phyllopsora furfuracea* and *Pyxine cocoës* were identified with isidia. Thirteen species of lichen did not possess any reproductive organs. *Parmotrema clavuliferum* has 2 reproductive organs, which are apothecia and soredia.

The predominant lichen thallus types among the various species were apothecia, soredia, and no reproduction with 22% thallus type, as shown in Figure 5. Apothecia are cup-shaped structures that contain the hymenium, which is composed of an apical structure without paraphyses, and an ascus that forms a thin layer extending to the inner surface of the cup. These structures are typically found in crustose lichens, with a diameter ranging from 0.5 to 3 mm. In larger foliose lichens, the diameter of the apothecia may reach 10-20 mm (Roth et al. 2021). Soredia, which are powdered forms within nodule-like soralium structures, give rise to new thalli under favorable conditions. Soredium hyphae develop from hyphae branching from the algal layer and encircling one or more algal cells (Zanetti et al. 2015). Changes in precipitation and temperature, particularly due to drought stress, will likely affect lichens the reproductive capacity. Soredia, the asexual reproductive structures of lichens, are influenced by macroclimatic factors; they are more prevalent in regions with lower microclimatic stress, higher radiation and temperatures, and lower humidity levels. Soredia are typically found on the upper parts of tree trunks, away from the ground, where microclimatic stress is greater. Conversely, apothecia, the sexual reproductive structures of lichens, are influenced by microclimatic conditions with favorable conditions typically leading to increased production of apothecia. They are more commonly observed at the base of trees and on north-facing surfaces, which tend to have higher moisture levels at specific latitudes (Martínez et al. 2012).

Distribution of lichen along pH gradient and host tree

The lichen community in the Bukit Barisan Mountain Forest Reserve is distributed based on pH, as shown in Figure 6.A. This community occupies forest areas within a pH range of 3 to 6, the number of lichen species at each pH level is as follows: 16 species at pH 3, 34 species at pH 4, 7 species at pH 5, and 11 species at pH 6, making a total of 68 species. However, it's worth noting that the total number of species is 57, as some species are found across multiple pH levels and tree species. The highest species diversity within the community was found at pH 4, with a total of 34 species. The correlation between pH and the lichen community exhibited a relatively weak correlation (r^2 = 0.207). Although the correlation between pH and the lichen community shows a low correlation, ecological conditions found at intermediate elevations can facilitate species' coexistence and interaction from lower and higher pH ranges, thereby increasing species diversity.

Our findings are consistent with McDonald et al.'s previous work (2017), indicating no substantial correlation between species count and substrate pH. While substrate pH does influence the composition of lichen communities, this influence is often overshadowed by the effect of tree species. The influence of tree species is more pronounced than bark pH in dominat lichen community composition. Despite the influence of substrate pH, the variability in tree species appears to play a dominant role in dictating lichen colonization.

Furthermore, in the present study, lichens were more commonly found in low-pH environments. The higher abundance of lichens in low-pH environments can be attributed to environments with low-pH supporting the growth and survival of certain lichen species. Some lichen species exhibit a preference or higher tolerance towards acidic environmental conditions; hence, they are more frequently found on substrates with a low pH. Also, low-pH environments can provide more optimal conditions for specific lichens' development and biological activities, such as increasing nutrient availability or reducing competition with other organisms (Nirhamo et al. 2021).

Figure 6.B shows that various types of lichen thalli depend on pH, with crustose and foliose thalli being more prevalent across different pH substrates. In contrast, the filamentous thalli were less represented. According to Shukla et al. (2014), crustose thalli are the most efficient among all thallus types due to their minimal water requirements and ability to retain water by adhering to the substrate.

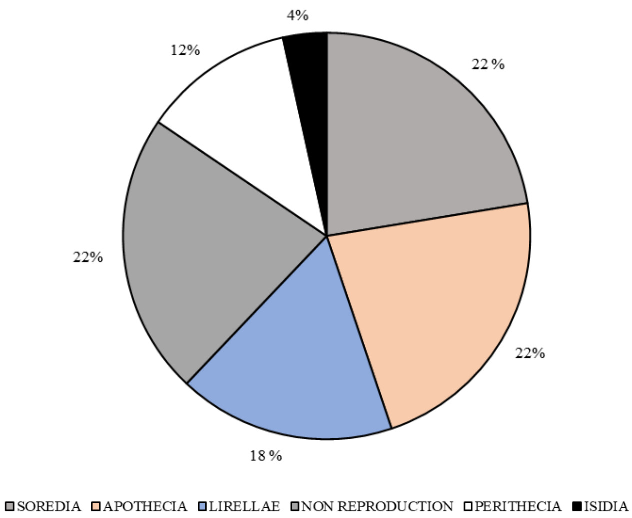
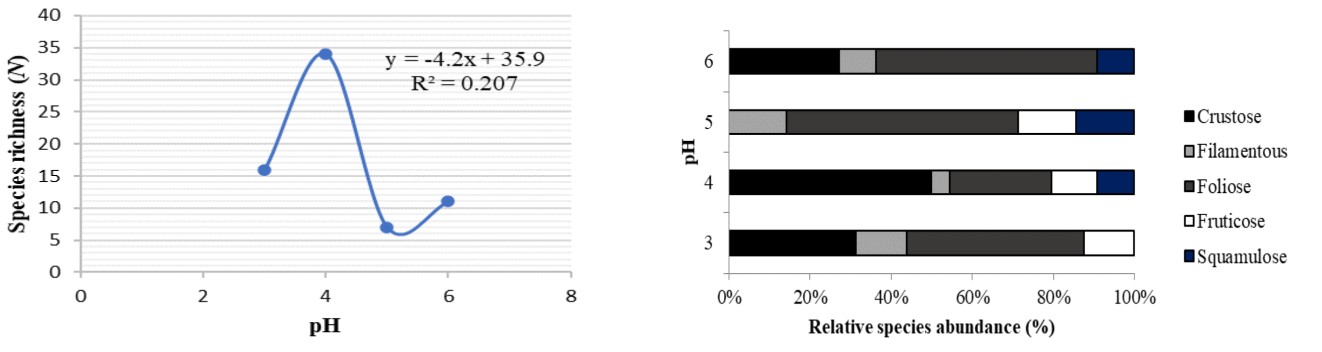


Figure 5. Percentage of lichen reproduction structure across species



A B

Figure 6. A. Total lichen species richness along pH gradient; B. The lichen percentage growth-form composition along the pH gradient recorded in Bukit Barisan Grand Forest Park, Bandar Baru Village

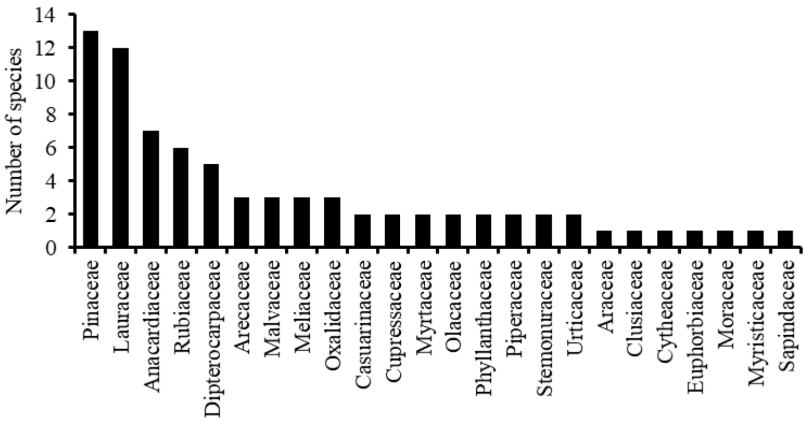


Figure 7. Distribution of number of lichen species occupying tree host by families

Crustose lichens, can therefore, tolerate a wide range of altitudes due to their ability to withstand extreme environmental conditions, such as temperature fluctuations, drought, and exposure to high levels of UV radiation (Armstrong 2017). The foliose thallus type, characterized by leaf-like lobes, is prevalent across different pH substrates but remains relatively sensitive to changes in environmental quality and is therefore intolerant to unsuitable habitats (Sujetovienė 2017; Balabanova et al. 2021). Consequently, it is found only under specific ecological conditions, often in areas with preserved ecosystems, such as the Bukit Barisan Grand Forest Park.

The study area included 33 host tree species belonging to 24 families. Pinaceae emerged as the primary host family, accommodating 13 lichen species, followed by Lauraceae with 12 species, as illustrated in Figure 7. *Pinus merkusii* provided the greatest support for lichen species among the host trees. This dominance of Pinaceae suggests this the family provides favorable ecological conditions conducive to the lichens thriving and maturation. Notov et al. (2015) discovered in their research on lichen composition on *Pinus sylvestris* trees that lichens were predominantly present on mature and aging trees. These older trees offer favorable conditions for epiphytic lichen growth and development because of their structural alterations and various ontogenetic stages, leading to diverse microenvironments. Therefore, the abundance and spread of lichens are significantly affected by variables, such as tree age, morphological configuration, and substrate characteristics. Hence, mature trees have emerged as crucial habitats for epiphytic lichens within forest ecosystems. Furthermore, in this research, the Lauraceae family was recognized as the second most extensively inhabited host tree by lichens following the Pinaceae family, accommodating up to 5 host species. According to Aththorick et al. (2018), in their research on the Bukit Barisan Grand Forest Park, the dominant vegetation in the forest belongs to the Lauraceae family; this high diversity of vegetation within the Lauraceae family in the Bukit Barisan Mountain Forest Park contributes factors to the abundance of lichen species growing in this family.

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