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Morphology of Lichen Fungi in Amban Regency, Manokwari, West Papua

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Abstract: Lichens are symbiotic association between fungi (mycobionts) and photosynthetic partners (phycobiont) that play essential ecological roles as bioindicators, pioneers in succession, and contributors to nutrient cycling. Despite their importance, the diversity and morphology of lichens in West Papua remain poorly documented. This study aimed to assess the morphology diversity of lichen taxa in Amban Regency, Manokwari, West Papua. The method used was explorative surveys with purposive sampling in Amban Regency (site I, II, and III) based on low, moderate, and high air quality. Lichen identification was based on morphological characteristic. The results showed that there were 27 species lichens belong to 12 genera and 8 families Chrysothrichaceae, Coenogoniaceae, Collemataceae, Graphidaceae, Megalosporaceae, Parmeliaceae, Physciaceae, and Strigulacea. The dominant species were from the families of Graphidaceae. Crustose lichens dominated (74%), foliose lichens (18%), with filamentous and leprose (4% each), while fruticose types were absent. Crustose lichens exhibited strong substrate adhesion and tolerance to variable microclimatic conditions with temperatures between 26,1-29,3°C, whereas foliose and filamentous forms were confined to more stable, and humid habitats between 72,0-85,4%. Continued surveys are recommended to monitor potential shifts in community composition under climate change and habitat disturbance.

Keywords: diversity, lichen, morphology, manokwari, papua.

Introduction

Lichens are symbiotic formed through the association of fungi (mycobionts) and photosynthetic partners typically algae or cyanobacteria, which coexist in a mutualistic relationship. The mycobiont provides structural support and protection, while the photobiont contributes organic carbon via photosynthesis (Spribille, 2023). Most lichen-forming fungi belong to Ascomycota with a smaller number classified within Basidiomycota. Photobionts are taxonomically diverse, including members of Chlorophyta, Ochrophyta, and Cyanobacteria. Beyond their taxonomic complexity, lichens are globally recognized as bioindicators, pioneers in ecological succesion, and contributors to nutrien cycling (Crittenden, 2022; Molins et al., 2021; Ramos et al., 2020).

Lichens as sensitive bioindicators of air quality, particularly because their thalli absorb atmospheric nutrients and pollutans directly without protective cuticles (Nimis & Martellos, 2022; Wan et al., 2023). Their distribution and morphological variation often reflect gradients of air pollution, microclimatic stability, and habitat integrity, making them valuable tools for monitoring environmental change. Despite this potential, Papua remains one of the most understudied global hotspots of lichen biodiversity (Huettmann, 2023). Recent work on tropical genera, such as *Peltigera*, reveals high levels of speciation and evolutionary novelty (Magain et al., 2023), suggesting that unexplored areas like Manokwari may harbor unique taxa and morphological diversity. However, systematic studies documenting lichen morphology in West Papua are scarce. This represents both a scientific challenge and an opportunity for advancing biodiversity research in the region. The novelty of this research lies in its focus on morphological variation at the family level in Amban Regency, where no detailed inventories have previously been reported.

Given the ecological importance, applied potential, and current lack of taxonomic documentation, studies of lichen morphology in Papua are urgently needed. This research therefore aims to document and analyze the morphological characteristics of lichen taxa in Amban Regency, Manokwari. The findings are expected to provide a baseline reference for biodiversity assessment and ecological monitoring in tropical environments increasingly threatened by climate change and habitat degradation (Aptroot, 2021; Singh & Upreti, 2022; Wan et al., 2023).

Method and Materials

Site Selection

The study area is located at Amban Regency Manokwari, West Papua. The study was conducted from September 2024 to November 2024. Lichen specimens were identified at Laboratory of Biology Faculty of Mathematics and Natural Sciences, University of Papua.

Data collection

The method used in this research is descriptive method with survey technique from three site. The sampling location or observation is determined by purposive sampling or intentionally with the location criteria is the lichen growing habitat. Abiotic factors observed in each site included temperature, humidity, and light intensity.

Sampling design

In Site I is good air quality and Site II is moderate air quality, site III is unhealhty air quality (Figur 1) and is characterized by areas near and far from main roads. Criteria of host five trees per site. The stem of the host tree that is used as the observation area. Four transparent plastic plots each measuring 4 cm x 20 cm.

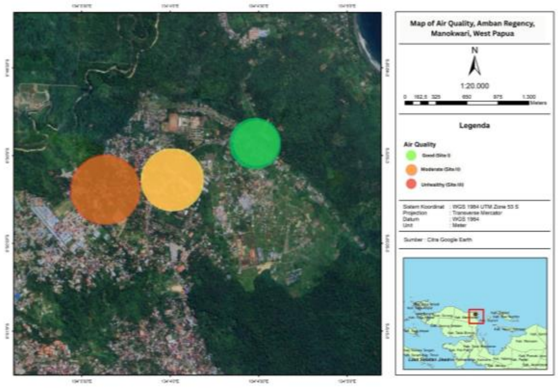


Figure 1. Map of lichen sampling

Collection of lichen

The samples of lichens were collected from the host tree using triangular blades. Types of lichens character are recorded in macroscopic characteristics using tally sheet. The samples store in an envelope and box collection, then given a label and decription. Equipment used in the research includes GPS (Global Position System) 76CSx Garmin maps, camera, air detectors, pH meter, 20x hand lup, meter fabric (cm), Microsoft Exel 2007, microscope stereo Nikon SMZ 645, microscope binokular Nikon YS 100, object glass, cover glass, pipet, pH meters, tweezers, triangular blades, roll meters, thermohigrometer, box collection. The materials are stationery (permanent snowman marker OHP OPF / 4S, 2B pencil, ruler, observation data sheet), paper envelope, four transparent plastic plots each measuring 4 cm x 20 cm (plastic OHP), tally sheet, millimeters of transparent blocks, Methylen blue, and razor blades.

Data analysis

The data obtained were analyzed descriptively simple, and displayed in the form of figure and tables.

Results and Discussion

Morphological diversity of Lichen Thalli

The survey recorded 27 species lichens belong to 12 genera and 8 families Chrysothrichaceae, Coenogoniaceae, Collemataceae, Graphidaceae, Megalosporaceae, Parmeliaceae, Physciaceae, and Strigulacea (Table 1).

Table 1. Morphological Forms of Lichens

No.	Genus	Species	Morphology
1.	*Chrysothrix*	*Chrysothrix xanthina*	Leprose
2.	*Strigula*	*Strigula* sp.	Crustose
3.	*Diorygma*	*Diorygma poitaei*	Crustose
4.	*Glyphis*	*Glyphis cicatricosa*	Crustose
5.	*Glyphis*	*Glyphis* sp.	Crustose
6.	*Graphis*	*Graphis immersella*	Crustose
7.	*Graphis*	*Graphis scripta*	Crustose
8.	*Phaeographina*	*Phaeographina* sp.1	Crustose
9.	*Phaeographina*	*Phaeographina* sp.2	Crustose
10.	*Phaeographis*	*Phaeographis australiensis*	Crustose
11.	*Phaeographis*	*Phaeographis elaeina*	Crustose
12.	*Phaeographis*	*Phaeographis* sp.	Crustose
13.	*Phaeographis*	*Phaeographis eludens*	Crustose
14.	*Phaeographis*	*Phaeographis pseudomelana*	Crustose
15.	*Phaeographis*	*Phaeographis subintricata*	Crustose
16.	*Sarcographa*	*Sarcographa labyrinthica*	Crustose
17.	*Phlyctis*	*Phlyctis argena*	Crustose
18.	*Haetomma*	*Haetomma* sp.	Crustose
19.	*Haetomma*	*Haematomma ochroleucum*	Crustose
20.	*Lecanora*	*Lecanora helva*	Crustose
21.	*Parmelia*	*Parmelia meiophora*	Foliose
22.	*Parmelia*	*Parmelia* sp.	Foliose
23.	*Parmotrema*	*Parmotrema tintorium*	Foliose
24.	*Dirinaria*	*Dirinaria picta*	Foliose
25.	*Megalospora*	*Megalospora melanodermia*	Crustose
26.	*Leptogium*	*Leptogium* sp.	Foliose
27.	*Coenogonium*	*Coenogonium nepalense*	Filamentous

The observationrevealed that the crustose lichen morphology type was found in greater abudance and predominated over the foliose and filamentous types, whereas the fructicose type wa entirely absent (Figure 2, Figure 3).

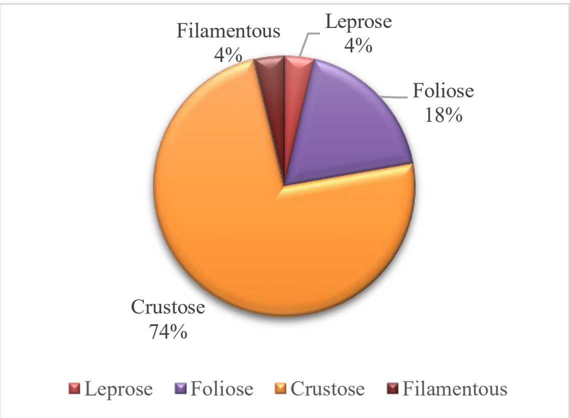
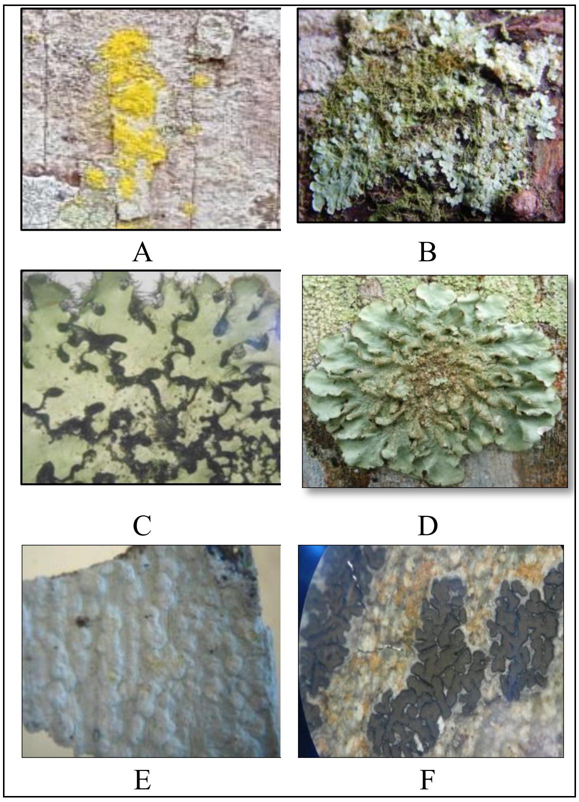


Figure 2. Morphology lichen



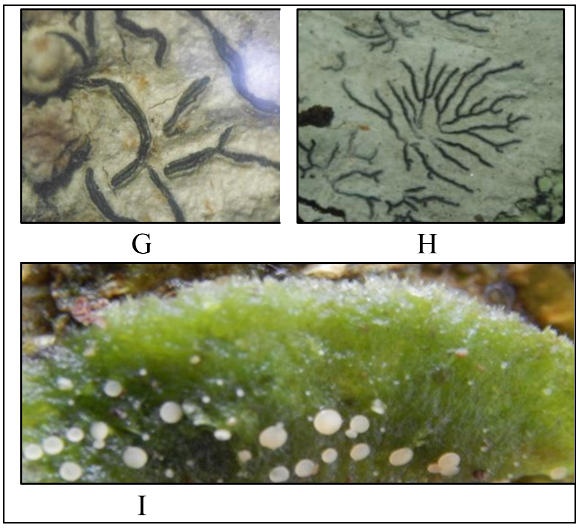


Figure 3. Morphology Leprose (A) *Chrisontrix xanthina,* Foliose (B) *Dirinaria picta*, (C) *Parmelia* sp., (D) *Parmelia meiophora*; Crustose (E) *Phlyctis argena,* (F-H) Graphidaceae; Filamentous (I) *Coenogonium nepalense*

Environment Parameters

The diversity and abundance of lichens are strongly influenced by several micro-environmental parameters, notably temperature, relative humidity, and substrate pH. These factors shape the physiological tolerance and colonization capacity of different lichen species (Table 2).

Table 2. Environment Paramaters

	Coordinate Point	T (°C) / H (%)	pH	Light Intensity (lux)	Air Quality
	Ligban street (0,83133° S, 134,07350° T) to (0,83325° S, 134,07618° T)	T: 26,1 H: 85,4	7-7,8	6.728	Good (HCHO: 0,006 mg/m^3; TVOC 0,009 mg/m^3; PM2.5: 25 ug/m^3; PM10: 32 ug/m^3; CO: 0 ppm; CO2: 405 ppm)
	Gunung salju street (0,83828° S, 134,06482° T) to (0,83318° S, 134,06842° T)	T: 27,4 H: 83,1	7,3-8,3	10.400	Moderate (HCHO: 0,158 mg/m^3; TVOC 1,101 mg/m^3; PM2.5: 21 ug/m^3; PM10: 27 ug/m^3; CO: 4 ppm; CO2 2.033 ppm)
III	Sumber jaya street ((0,83314° S, 134,06145° T) to (0,84047° S, 134,05957° T)	T: 29,3 H: 72,0	5-8,6	14.533	Unhealthy (HCHO: 0,220 mg/m^3; TVOC: 1,850 mg/m^3; PM2.5: 88 ug/ m^3; PM10: 130 ug/ m^3; CO: 15 ppm; CO2: 3.150 ppm)

T (temperature), H (humidity), pH bark tree

Site I (good air quality) exhibited very low pollutant levels, with HCHO recorded at only 0.006 mg/m³, TVOC at 0.009 mg/m³, PM2.5 at 25 µg/m³, PM10 at 32 µg/m³, CO at 0 ppm, and CO_2 at 405 ppm. These findings indicate that the air quality remains within the good category, typically associated with areas containing natural vegetation or minimal anthropogenic activities. Site II (moderate air quality) showed a notable increase in HCHO (0.158 mg/m³), TVOC (1.101 mg/m³), and CO_2 concentrations, which escalated to 2033 ppm. Although PM2.5 (21 µg/m³) and PM10 (27 µg/m³) levels were relatively lower compared to Site I, the elevated concentrations of volatile organic compounds and CO suggest contributions from human activities, possibly originating from indoor sources or localized activities not directly related to traffic emissions.

Site III (unhealthy air quality) recorded substantially higher pollutant concentrations, with HCHO at 0.220 mg/m³, TVOC at 1.850 mg/m³, PM2.5 at 88 µg/m³, PM10 at 130 µg/m³, CO at 15 ppm, and CO_2 at 3150 ppm. This site was located near a major roadway with heavy vehicular traffic, indicating that the primary sources of pollutants were motor vehicle emissions. Elevated PM2.5 and PM10 levels are strongly associated with incomplete combustion of fossil fuels, while CO and VOCs (Volatile Organic Compounds) represent characteristic emissions from transportation sources. Classification within the unhealthy category implies significant health risks for the population, particularly vulnerable groups such as children, the elderly, and individuals with pre-existing respiratory or cardiovascular conditions.

Discussion

Lichen Identification

The family Graphidaceae is notable for its crustose thalli and distinctive ascomata commonly lirelliform (elongated), slit-like, or hieroglyph-like structures embedded within the thallus. These morphological features are evolutionarily significant and have undergone parallel evolution across multiple lineages, shaped more by ecological constraints than by strict phylogenetic heritage (Gogoi et al., 2021).

In the Parmeliaceae, morphological diversity includes foliose thalli with well-developed upper cortex, medulla, and a lower cortex bearing rhizines. These features are adaptive traits facilitating adherence, gas exchange, and resilience under varying microclimatic conditions (Singh et al., 2020). Similarly, *Dirinaria picta* develops a foliose thallus of orbicular, irregular lobes, a morphology that allows survival in semi-urban environments with moderate levels of atmospheric pollutants (Wan et al., 2023).

Other lichen families exhibit highly specialized traits. The Coenogoniaceae (*Coenogonium nepalense*) forms filamentous thalli with densely interwoven Trentepohlia photobionts, maximizing efficiency in high-humidity microhabitats (Cáceres et al., 2021). The Collemataceae, such as *Leptogium* species, are characterized by gelatinous *Nostoc*-based thalli that maintain hydration over extended periods, rendering them highly sensitive to desiccation and useful as moisture indicators (Matos et al., 2021). The Chrysotrichaceae, with their bright golden crustose thalli rich in pulvinic acid derivatives, are restricted to humid bark substrates in tropical and subtropical forests, where pigment production confers both protective and ecological functions. The Strigulaceae remain distinctive for their folicolous habit, colonizing living leaf surfaces in shaded, humid environments but declining under canopy disturbance (Jiang et al., 2020).

Family Strigulaceae exhibit an ecologically distinctive folicolous habit, predominantly colonizing living leaf surface in shaded and humid microhabitats. Their thin, epiphylic thalii, with pale green to olive pigmentation, provide effective camouflage against the leaf substrate, while the perithecioid apothecia represent morphological specialization to the spatial constrainsts of leaf surfaces (Jiang et al., 2020). Nevertheless, their dependence on consistently high humidity renders them vulnerable to microclimatic fluctuations, especially those caused by anthropogenic canopy alteration.

Family Haematommataceae are notable for their apothecia with vivid blood-red discs, a coloration derived from anthraquinone pigments. Their tightly appressed crustose thalii enhance resilience in high-altitude environments characterized by low temperatures and pristine air quality. Moreover, the presence of green algal photobionts confers tolerance to elevated light intensities typically encountered at mid to high elevation habitats. Anthraquinone Pigmentation (Haematommataceae like Traits). Although precise studies on Haematommataceae remain limited, recent research on *Xanthoria parietina* a model anthraquinone-bearing lichen—sheds light on the ecological functions of bright pigments. Daminova et al. (2024) demonstrate that parietin not only enables UV protection but also enhances desiccation tolerance by stabilizing membrane structure, reducing lipid peroxidation, and increasing water-holding capacity through changes in upper cortex morphology. The antioxidant properties and anatomical modifications support survival in high-altitude or high-UV environments, implying that similar traits in Haematommataceae yield analogous adaptive benefits (Daminova et al., 2024).

Family Caliciaceae, whose mazaediate apothecia produce dry, darkly pigmented spore masses that were efficiently dispersed by wind in exposed or air condition. Their thallus forms vary form crustose, with strong preference for aged substrate such as decayed wood, rock surfaces, or historical masonry. The thick-walled, melanized spores provide structural and chemical protection against ultraviolet radiation and prolonged desiccation. Recent investigations into UV-induced melanisation in foliose lichens, particularly *Lobaria pulmonaria*, reveal critical defensive functions of melanin. Studies show that UV-B exposure triggers melanin biosynthesis, thickening the upper cortex and enhancing drought tolerance by improving water retention (Kann et al., 2025). Moreover, ultrastructural analyses using atomic force microscopy (AFM) demonstrate that melanized thalli develop smoother cortex relief and reduced adhesiveness, protecting cell walls under high-irradiance stress (Daminova et al., 2023). These findings support the inference that crustose lichen families like Caliciaceae which possess melanized spores and thalli employ similar mechanisms, enabling survival in exposed, UV-intensive environments

Family Megalosporaceae present either foliose or crustose thalli accompanied by conspicuously large apothecia and exceptionally large ascospores (> 100 µm). The association with Trebouxia photobionts further optimizes photosynthesis under low-light conditions resulting from dense canopy cover. Large Ascospores and Photobiont Dynamics (Megalosporaceae like Traits). Emerging genomic and ecological insights into *Trebouxia* photobionts highlight their extensive diversity and adaptive significance. Jung et al. (2024) reveal multiple ecologically distinct lineages of *Trebouxia*, each associated with specific photic and climatic niches. Though direct studies on Megalosporaceae are sparse, the association with Trebouxia suggests that lichens housing such photobionts benefit from optimized photosynthetic performance under low-light conditions (Jung et al., 2024).

Large-spored crustose/folliose taxa, characterized by substantial reproductive structures, likely compensate for limited light by maximizing photoefficiency and ensuring reproductive success under dense canopies. Anthraquinone Pigmentation (e.g., parietin) functions as both a photoprotectant and a desiccation buffer, enabling lichens to endure high-radiation and arid environments (Daminova et al., 2024). Melanin Accumulation confers UV and drought resilience through structural reinforcement and water retention, supporting lichen persistence in exposed microhabitats (Kann et al., 2025; Daminova et al., 2023). Photobiont Adaptation (*Trebouxia* diversity) suggests that lichens with large spores and efficient photobiont partnerships thrive under low-light conditions, such as dense forest canopies (Jung et al., 2024).

Lichen Morphology Type

The dominance of crustose lichens can be attributes to their morphological trair of firmly adhering to the substrate, which renders them more resilient to extreme environmental condition such as fluctuation in humidity, high light intensity, and nutrient limitation (Candan et al., 2020). The tighly attached thallus structure also reduces water loss and protects the photobiont from direct solar radiation, theby cofferring a competitive advantage in open habitats or on hard substrates such as rocks (Malicek et al., 2021).

Foliose and Filamentous morphology type lichen require more stable moisture conditions and were generally less tolerant of drought or intense radiation. This limits their distribution to specific microhabitats such as tree bark surfaces or shaded areas (Singh et al., 2021). The absence of fructicose lichens is most likely related to their requirement for high air humidity, diffuse light, and clean air (Hauck et al., 2020). In study areas characterized by high exposure, low humidity, or air pollution, fructicose lichens are unlikely to thrive. The variation in thallus morphology among lichenized fungi reflects complex adaptive strategies to environmental gradients, ranging from moisture and light availability to air quality. Recent studies have shown that climate change and habitat degradation can influence the distribution to specific thallus types, whis in turn affects the composition of lichen communities within an ecosystem (Munzi et al., 2020; Cornejo & Scheidegger, 2022).

Air Quality Assesment

The clear gradient across the site I (low), site II (moderate to high), and III (high) confirms the use of lichens as reliable bioindicators of air quality. In contrast, Site 3 with natural substrates (tree bark) exhibited substantially higher lichen morphology diversity, with a strong dominance of crustose lichens from Graphidaceae. Tree bark with stable surfaces and nutrient-rich microenvironments provides favorable conditions for corticolous lichens, enabling higher species richness compared to inorganic substrates (Nimis & Martellos, 2022). Comparable results were reported by Aptroot (2021) in Papua, where richness of corticolous (tree bark) lichens correlated with reduced levels of atmospheric pollutants.

Wan et al. (2023) reported that the presence of *Dirinaria picta* is frequently associated with urban or semi-urban environments characterized by moderate levels of air pollution. Thus, the restricted species diversity observed at both sites underscores the unsuitability of inorganic substrates for supporting high lichen diversity, while also reflecting relatively lower air quality compared to natural substrates.

Lichen community composition at the three sampling sites reflects variation in local air quality. In Site I dan II, lichens *Graphidaceae*, *Strigula* sp., and *Dirinaria picta*, indicates moderate to high air quality. The presence of foliose lichens such as *Dirinaria picta* suggests that pollutants are not at levels that suppress sensitive morphotypes. Crustose taxa of Graphidaceae further demonstrate the availability of humid and relatively stable microhabitats, consistent with forest-dominated landscapes (Singh & Upreti, 2022). In contrast, Site III showed low air quality, as indicated by the reduced richness and dominance of highly stress-tolerant taxa (*Strigula* sp. with white thallus). The scarcity of foliose and sensitive species in this site reflects greater exposure to anthropogenic disturbance, possibly linked to vehicle emissions, infrastructure, or reduced canopy cover. Similar patterns have been reported in urban lichen monitoring, where crustose forms dominate under pollutant stress while foliose and fruticose forms decline (Nimis & Martellos, 2022; Wan et al., 2023).

Air quality in Site III was categorized as high, which corroborates the role of lichens as bioindicators. Corticolous lichens, particularly Graphidaceae, are known to be sensitive to atmospheric changes and are more abundant in areas with low levels of pollution (Crittenden, 2022). These results suggest that areas in Amban remain relatively intact, sustaining more complex lichen communities.

Ecological Implications

The result indicate variation in light intensity (lux) across the Site I, recorded the highest temperature (29,3°C) and the highest light intensity (14.533 lux), indicating a relatively open area with direct sunlight exposure. Such condition are typically found in habitats with fragmented canopy cover. High-light intensity habitats reduced humidity and temperature fluctuations, can influence the distribution and abundance of lichens, particulary morphology crustose lichens that greater tolerance (Song et al., 2021; Nelson et. al., 2022).

Site II, exhibited the lowest temperature (26,1°C) and the lowest light intensity (6.728 lux), indicating a shaded location with dense canopy cover. High vegetation density reduces light intensity, and more stable humiditysupport lichens that are sensitive to hight irradiance and require consisten moisture availability, including morphology foliose and filamentous lichens (Rozema et. al., 2017; Matos et.al., 2021).

Site III, presented intermediate with a temperature (27,4°C) and a light intensity of 10.400 lux, classifying it as semi-open. Partial canopy openings in such areas allow moderate light intensity, producing a blend of microclimatic characteristic both open and shaded habitats. Transitional zones of this nature often sustain higher lichen diversity, as they can accommodate species with a broad tolerance range for light availability (Lakatos et. al., 2006; Singh & Nayaka, 2020). This variability was direct implications for lichen morphology variation, as differences in light intensity influence photobiont photosintetic (algae or cyanobacteria) and mycobionts in lichen and also the morphological adaptations of the thallus (Mugia et al., 2020; Bellenger et al., 2023).

The gradient observed across Site I (Good), Site II (Moderate), and Site III (Unhealthy) strongly supports the role of lichens as sensitive bioindicators of air quality. At Site I, the presence of higher morphological diversity, including foliose taxa such as Dirinaria picta alongside members of Graphidaceae, indicates that humid and relatively unpolluted microhabitats favor morphotypes with higher surface area and differentiated anatomy. Comparable findings were reported by Aptroot (2021) in Papua, where corticolous lichens displayed greater richness in low-pollution forests, demonstrating the strong link between pollutant loads and lichen diversity. Recent work by Correa-Ochoa et al. (2021) also confirms that foliose and fruticose lichens exhibit a negative correlation with particulate matter (PM2.5), making them reliable proxies for clean-air conditions.

At Site II, the persistence of Dirinaria picta suggests tolerance to moderate levels of pollution. This observation aligns with studies by Wan et al. (2023), who documented the resilience of certain foliose lichens in urban Chinese environments characterized by moderate nitrogen oxides (NOx) and particulate matter exposure. Similarly, Styburski et al. (2023) found that Physcia adscendens maintained

photosynthetic capacity and structural adaptation under moderate urban stressors, further supporting the conclusion that some foliose taxa can survive intermediate levels of air pollution. Crustose lichens were also common at this site, indicating that while pollutants were present, conditions had not yet reached thresholds that entirely exclude sensitive foliose morphotypes.
In sharp contrast, Site III exhibited reduced richness, near absence of foliose taxa, and dominance of highly tolerant crustose species such as Strigula sp. This shift in community composition is strongly associated with vehicular emissions, particularly CO, VOCs, and fine particulate matter. These findings parallel urban biomonitoring studies in Europe and Asia, where crustose lichens dominate under pollution stress while foliose and fruticose forms rapidly decline (Nimis & Martellos, 2022; Wan et al., 2023). Furthermore, Lawal et al. (2023) applied association rule mining in Nigerian cities and found strong statistical links between crustose taxa and polluted urban sites, reinforcing the robustness of crustose forms as indicators of degraded air quality.

The compositional shifts across sites—from diverse foliose and corticolous taxa at low-pollution sites to crustose-dominated assemblages under high anthropogenic stress—confirm that lichen communities mirror air-quality gradients. Sensitive foliose taxa act as early-warning indicators of atmospheric degradation, while crustose species persist as the dominant morphotypes in heavily polluted microenvironments. These results, supported by recent empirical evidence (Correa-Ochoa et al., 2021; Styburski et al., 2023; Lawal et al., 2023), underscore the ecological and bioindicator value of lichens for urban and peri-urban air quality monitoring.

Conclusion

The lichen taxa studied exhibit notable morphological variation. 27 species lichens belong to 12 genera and 8 families. Morphology of lichens were dominated by crustose types (74%), followed by foliose (18%), and filamentous or leprose forms (4% each), with fruticose lichens absent. Crustose lichens dominate due to their strong substrate adhesion and tolerance to environmental extremes, while foliose and filamentous forms are confined to stable, humid microhabitats, and fruticose lichens are absent, likely due to their stringent moisture and air quality requirements. High species richness and the presence of foliose taxa at low-pollution sites contrast with the reduced diversity and dominance of crustose forms under higher anthropogenic stress. These patterns demonstrate that lichens provide a sensitive and cost-effective tool for monitoring atmospheric quality in varying ecological settings.

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Reference

Aptroot, A. (2021). Lichens from lowland forests in Papua: Indicators of intact habitats. Willdenowia, 51(2), 205–217. https://doi.org/10.3372/wi.51.51209

Aptroot, A. (2021). Lichens from New Guinea: New species and new records. Australasian Lichenology, 88, 50–64. https://doi.org/10.11646/cabrev.2021.88.2

Bellenger, L., Baurain, D., Lutzoni, F., & Magain, N. (2023). Microclimate and photobiont adaptation in tropical lichen communities. Fungal Diversity, 122(1), 45–63. https://doi.org/10.1007/s13225-023-00525-9

Benesperi, R., Bianchi, E., Brunialti, G., et al. (2021). Functional traits of lichens respond to forest management and air quality. Forest Ecology and Management, 479, 118567. https://doi.org/10.1016/j.foreco.2020.118567

Candan, M., Halici, M. G., & Aksoy, A. (2020). Substrate preference and diversity of crustose lichens in relation to rock type and microhabitat. The Lichenologist, 52(4), 271–283. https://doi.org/10.1017/S0024282920000195

Cornejo, C., & Scheidegger, C. (2022). Lichen functional traits and responses to climate change. Fungal Diversity, 112, 105–124. https://doi.org/10.1007/s13225-021-00492-4

Correa-Ochoa, M. A., Lücking, R., & Herrera-Campos, M. A. (2021). Spatial distribution of corticolous lichens as indicators of air quality in urban environments. Revista de Biología Tropical, 69(3), 789–803. https://doi.org/10.15517/rbt.v69i3.45085

Crittenden, P. D. (2022). Lichens as environmental indicators. Plants, People, Planet, 4(2), 123–134. https://doi.org/10.1002/ppp3.10218

Crittenden, P. D. (2022). Lichens as environmental indicators: Past, present and future. Fungal Ecology, 56, 101144. https://doi.org/10.1016/j.funeco.2021.101144

Daminova, A. G., et al. (2023). Topography of UV-melanized thalli of Lobaria pulmonaria: Structural adaptations revealed by AFM and SEM. Plants, 12(14), 2627. https://doi.org/10.3390/plants12142627

Daminova, A. G., Leksin, I. Y., Khabibrakhmanova, V. R., Gurjanov, O. P., Galeeva, E. I., Trifonova, T. V., Khamatgalimov, A. R., Beckett, R. P., & Minibayeva, F. V. (2024). The roles of the anthraquinone parietin in the tolerance to desiccation of the lichen Xanthoria parietina: Physiology and anatomy of the pale and bright-orange thalli. International Journal of Molecular Sciences, 25(13), 7067. https://doi.org/10.3390/ijms25137067

Fryday, A. M., Wheeler, T. B., & Etayo, J. (2021). A new species of Aspicilia (Megasporaceae)… The Lichenologist, 53, 307–315. https://doi.org/10.1017/S0024282921000244

Hauck, M., de Bruyn, U., & Leuschner, C. (2020). Air pollution tolerance in lichens: A review. Environmental and Experimental Botany, 170, 103882. https://doi.org/10.1016/j.envexpbot.2019.103882

Huettmann, F. (2023). Biodiversity of lichens in Papua: A global hotspot under pressure. Biodiversity and Conservation, 32(6), 1501–1518. https://doi.org/10.1007/s10531-023-02678-1

Jiang, S. H., Lücking, R., & Wei, J. C. (2020). Taxonomy and diversity of foliicolous lichens in tropical Asia. MycoKeys, 68, 95–116. https://doi.org/10.3897/mycokeys.68.51913

Jung, P., et al. (2024). Trebouxia: The dominant organism fueling the ecosystem of the grit crust. Environmental Microbiome, 19(1), 1–15. https://doi.org/10.1186/s40793-024-00601-5

Kalb, K., Rivas Plata, E., Lücking, R., & Bungartz, F. (2018). Taxonomy and phylogeny of the family Megalosporaceae (lichenized Ascomycota). The Lichenologist, 50(2), 161–178. https://doi.org/10.1017/S0024282918000057

Kann, I. K., Solhaug, K. A., & Gauslaa, Y. (2025). Ultraviolet radiation: A double-edged sword in old-forest lobaria lichens—Reducing growth while enhancing acclimation. Oecologia. https://doi.org/10.1007/s00442-025-05765-6

Kistenich, S., Timdal, E., Bendiksby, M., & Ekman, S. (2018). Molecular systematics and taxonomy of Haematommataceae (Lecanorales, lichenized Ascomycota). Mycologia, 110(6), 1055–1074. https://doi.org/10.1080/00275514.2018.1502702

Kranner, I., Beckett, R., Hochman, A., & Nash, T. H. (2020). Photosynthetic performance of lichens under different light and humidity regimes. The Lichenologist, 52(5), 305–319. https://doi.org/10.1017/S0024282920000270

Kranner, I., Beckett, R., Hochmuth, T., & Nash, T. H. (2020). Desiccation-tolerance in lichens: A mechanistic overview. Fungal Biology Reviews, 34(1), 1–14. https://doi.org/10.1016/j.fbr.2020.01.001

Lakatos, M., Büdel, B., & Lange, O. L. (2020). Ecophysiological strategies of lichens in contrasting light environments. Fungal Ecology, 47, 100936. https://doi.org/10.1016/j.funeco.2020.100936

Lakatos, M., Rascher, U., & Büdel, B. (2006). Functional characteristics of corticolous lichens in the understory of a tropical lowland rainforest. New Phytologist, 172(4), 679–695. https://doi.org/10.1111/j.1469-8137.2006.01885.x

Lawal, O., Lajide, L., & Akinmoladun, F. O. (2023). Mining association rules between lichens and air quality: Implications for biomonitoring in Nigerian cities. Environmental Pollution, 315, 120–130. https://doi.org/10.1016/j.envpol.2022.120130

Magain, N., Gueidan, C., & Sérusiaux, E. (2023). Diversification of the genus Peltigera in tropical ecosystems. Molecular Phylogenetics and Evolution, 178, 107620. https://doi.org/10.1016/j.ympev.2023.107620

Malíček, J., Palice, Z., & Vondrák, J. (2021). Crustose lichen diversity in different microhabitats and rock types. Biodiversity and Conservation, 30, 2601–2620. https://doi.org/10.1007/s10531-021-02210-5

Matos, P., Pinho, P., & Branquinho, C. (2021). Shaping lichen communities: Microclimatic drivers of diversity in Atlantic forest remnants. Science of the Total Environment, 753, 142008. https://doi.org/10.1016/j.scitotenv.2020.142008

Matos, P., Pinho, P., & Ribeiro, C. (2021). Microclimate drivers of epiphytic lichen diversity across forest canopies. Biodiversity and Conservation, 30(12), 3483–3501. https://doi.org/10.1007/s10531-021-02224-4

Matwiejuk, A., & Kukwa, M. (2022). Diversity patterns of epiphytic lichens along light and moisture gradients. Biodiversity and Conservation, 31, 2169–2185. https://doi.org/10.1007/s10531-022-02446-5

Molins, A., Martín, M. P., & Gaya, E. (2021). Lichen symbiosis: Functional and evolutionary perspectives. Fungal Diversity, 107(1), 1–23. https://doi.org/10.1007/s13225-020-00461-7

Muggia, L., Nelsen, M. P., Kirika, P. M., & Divakar, P. K. (2020). The role of photobionts in the diversification of lichen symbioses. New Phytologist, 227(2), 375–382. https://doi.org/10.1111/nph.16522.x

Muggia, L., Pérez-Ortega, S., Kopun, T., & Zellnig, G. (2020). Morphological diversity and adaptation strategies in lichens. Journal of Fungi, 6(4), 259. https://doi.org/10.3390/jof6040259

Munzi, S., Giordani, P., & Paoli, L. (2022). Air pollution, climate change, and lichen ecology: Emerging patterns and implications. Ecological Indicators, 141, 109070. https://doi.org/10.1016/j.ecolind.2022.109070

Munzi, S., Pisani, T., & Loppi, S. (2020). Environmental drivers of lichen diversity and distribution: A review. Ecological Indicators, 118, 106724. https://doi.org/10.1016/j.ecolind.2020.106724

Nelson, P. R., St. Clair, L. L., & Root, H. T. (2022). Light and temperature tolerances in crustose lichens: Implications for climate change resilience. The Lichenologist, 54(3), 147–160. https://doi.org/10.1017/S0024282922000086

Nimis, P. L., & Martellos, S. (2020). A literature-based worldwide checklist of lichens and lichenicolous fungi: Current knowledge and perspectives for future research. Plants, 9(8), 889. https://doi.org/10.3390/plants9080889

Nimis, P. L., & Martellos, S. (2022). Lichens as bioindicators of air pollution: A review of recent developments. Ecological Indicators, 135, 108527. https://doi.org/10.1016/j.ecolind.2022.108527

Nimis, P. L., & Martellos, S. (2022). Lichens as indicators of air pollution: A global overview. Ecological Indicators, 137, 108783. https://doi.org/10.1016/j.ecolind.2022.108783

Nimis, P. L., & Martellos, S. (2022). Lichens as indicators of environmental quality and climate change. Ecological Indicators, 142, 109-203. https://doi.org/10.1016/j.ecolind.2022.109203

Prieto, M., & Wedin, M. (2017). Phylogeny, taxonomy and diversification events in the lichen family Caliciaceae (Ascomycota, Lecanoromycetes). Molecular Phylogenetics and Evolution, 111, 11–29. https://doi.org/10.1016/j.ympev.2017.03.006

Purvis, O. W. (2020). Lichens and environmental change: Monitoring with a global perspective. The Lichenologist, 52(3), 165–180. https://doi.org/10.1017/S0024282920000187

Ramos, V., Morillas, L., & Barreno, E. (2020). Lichens in ecosystem functioning and biogeochemical cycles. Biogeosciences, 17(12), 3215–3228. https://doi.org/10.5194/bg-17-3215-2020

Rozema, J., et al. (2017). The role of UV-B radiation in lichen ecology. Environmental and Experimental Botany, 140, 4–17. https://doi.org/10.1016/j.envexpbot.2017.05.009

Singh, C. P., Upreti, D. K., Raju, A., & Shukla, V. (2022). A geostatistical approach to compare metal accumulation pattern by lichens in plain and mountainous regions of northern and central India. Environmental Earth Sciences, 81(7), 1–13. https://doi.org/10.1007/s12665-022-10336-6

Singh, G., & Nayaka, S. (2020). Diversity patterns of lichens along canopy openness gradients in Indian tropical forests. Bryologist, 123(4), 592–605. https://doi.org/10.1639/0007-2745-123.4.592

Singh, K. P., Upreti, D. K., & Sharma, R. (2020). Influence of light and microclimate on lichen communities in tropical dry forests. Journal of Forestry Research, 31(2), 593–602. https://doi.org/10.1007/s11676-019-00888-w

Singh, P., Upreti, D. K., & Rawat, R. (2021). Diversity and distribution of foliose lichens in relation to environmental factors. Plant Biosystems, 155(6), 965–976. https://doi.org/10.1080/11263504.2020.1779835

Song, L., Liu, W., & Hu, S. (2021). Effects of canopy openness on microclimate and lichen communities in subtropical forests. Forest Ecology and Management, 479, 118598. https://doi.org/10.1016/j.foreco.2020.118598

Song, L., Wang, X., & Li, H. (2021). Effects of microclimate on lichen community structure in subtropical montane forests. Forest Ecology and Management, 480, 118692. https://doi.org/10.1016/j.foreco.2020.118692

Spribille, T. (2023). The hidden diversity of lichen symbioses. Nature Reviews Microbiology, 21(5), 285–300. https://doi.org/10.1038/s41579-022-00785-7

Styburski, J., Fałtynowicz, W., & Mleczek, M. (2023). Do urban air pollutants induce structural changes in the thallus of Physcia adscendens? Scientific Reports, 13, 10445. https://doi.org/10.1038/s41598-023-37390-1

Teloschistaceae pigments and evolution (2023). Recent comparative genomics highlight anthraquinone biosynthetic clusters across Teloschistales lineages.

The Roles of the Anthraquinone Parietin in the Tolerance to Desiccation of the Lichen Xanthoria parietina: Physiology and Anatomy of the Pale and Bright-Orange Thalli (2024). Journal detailing parietin's protective roles.

Ultraviolet-induced melanisation in lichens: physiological traits and transcriptome profile (2024). Transcriptome evidence of melanin in response to UV-B.

Wan, Y., Li, X., & Wang, L. (2023). Responses of foliose lichens to urban air pollutants in subtropical China. Environmental Monitoring and Assessment, 195(6), 722. https://doi.org/10.1007/s10661-023-11592-9

Wan, Y., Zhang, Y., & Li, W. (2023). Lichens as bioindicators of atmospheric pollution: Advances and challenges. Environmental Pollution, 316, 120599. https://doi.org/10.1016/j.envpol.2022.120599

Wan, Y., Zhang, Y., Wang, L., & Liu, W. (2023). Lichens as sensitive indicators of atmospheric pollution: Advances and perspectives. Environmental Pollution, 326, 121601. https://doi.org/10.1016/j.envpol.2023.121