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Baseline Inventory, Taxonomic Identification and Characterization of Lichens at Sophia Point Rainforest Research Centre, Essequibo River, Guyana

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Abstract

Lichens are good indicators of environmental conditions, yet their diversity in inland Guyana remains poorly documented. This study identified and characterized lichens at the Sophia Point Rainforest Research Centre located near the confluence of the Essequibo, Mazaruni, and Cuyuni rivers. A quantitative, non-experimental observational approach was used. Suitable host trees were purposively selected, and lichen communities were examined within a standardized bark zone approximately 1.5 m above ground level. Field identification was based on thallus morphology, growth form, colour, attachment, lobation, surface characteristics and reproductive structures, while representative specimens were examined in the laboratory and chemical spot tests were applied where necessary. Sixteen lichen taxa were recorded, representing a broad range of foliose, crustose, fruticose and crustose-leprose growth forms. Foliose taxa were the most conspicuous component of the assemblage. Chemical spot testing provided additional diagnostic information, with species displaying distinctive K, C, KC and P reactions as well as predominantly negative profiles. The observed diversity suggests that the bark substrate provides heterogeneous microsites capable of supporting lichens with contrasting structural and reproductive characteristics. The study establishes a baseline for lichen diversity at Sophia Point and contributes to the body of lichenological knowledge from inland Guyana. Continued inventories across additional host species, habitats and seasons, supported by detailed taxonomic verification, are recommended to improve understanding of lichen diversity, distribution and ecological significance and conservation in Guyana.

Keyword: Lichens, Lichen diversity, Sophia Point, Guyana

1. Introduction

Biology, Ecology and Importance of Lichens

Lichens are stable symbiotic associations involving a fungal partner (mycobiont) and one or more photosynthetic partners (photobionts), usually green algae or cyanobacteria [82]. They represent one of the most successful examples of mutualism in nature and are capable of colonizing diverse substrates including rocks, soil, leaves and tree bark. Corticolous lichens, which inhabit bark surfaces, constitute one of the largest and most diverse ecological groups [37].

Approximately 20,000 species have been described worldwide, although the actual number is believed to be

substantially higher, particularly in tropical ecosystems [79]. Tropical forests harbour exceptionally rich epiphytic communities owing to their structural complexity and favourable microclimatic conditions [3, 39]. Host-tree characteristics, including bark pH, bark texture, water-holding capacity, age, and chemical composition, strongly influence lichen colonization and species composition [45, 61].

Lichens perform numerous ecological functions. They contribute to nutrient cycling, weathering processes, carbon sequestration, and water interception [82]. Cyanolichens are particularly important because they fix atmospheric nitrogen and enhance soil fertility [89]. Owing to their poikilohydric physiology and ability to absorb substances directly from the atmosphere, lichens are highly sensitive to environmental disturbances and have long been employed as biomonitors of air quality, heavy metal contamination and climate change [42, 86].

Changes in lichen community composition often reflect habitat fragmentation and anthropogenic disturbances, making them useful indicators for assessing forest continuity and ecological integrity [46], conservation planning and biodiversity assessments [55].

Diversity and Current Status of Lichen Research in Guyana

Despite being situated within the biologically rich Guiana Shield, lichenological research in Guyana has remained relatively underdeveloped. Consequently, although there have been collections and studies from various regions of Guyana, the country's lichen biota still remains poorly documented, with relatively limited research on lichens across many terrestrial ecosystems. Recent research on lichens has included studies in coastal, urban, and suburban environments, highlighting the need for more studies on lichen communities in inland and forest ecosystems.

One of the earliest extensive treatments of tropical lichens in the Guiana region was undertaken by Aptroot & Sipman (1997) [3], who highlighted the exceptional richness of the Guiana Shield and predicted the existence of many undescribed taxa. Subsequent taxonomic investigations by Aptroot (2016) [2] described several species from Guyana, including *Astrothelium corallinum*, *A. lucidothallinum* and *A. megatropicum*, demonstrating the country's importance as a centre of lichen diversity.

One of the most recent investigations into corticolous lichens in Guyana were conducted by Bacchus & Da Silva (2021) [11], who examined host plant specificity in urban and suburban habitats in New Amsterdam, Berbice. Their study demonstrated that phorophyte identity significantly influenced species occurrence and community composition, suggesting that bark characteristics and microenvironmental conditions act as important determinants of lichen establishment. Importantly, the authors highlighted the existence of species-specific host preferences, thereby challenging the assumption that corticolous lichens are distributed indiscriminately among available substrates [11, 14]. These findings provided the first empirical evidence of host specificity among Guyanese lichen communities and established a foundation for subsequent ecological investigations.

Building upon this work, Bacchus & Da Silva (2023) [12] conducted a more comprehensive survey of corticolous lichens associated with urban and suburban trees in New Amsterdam. Their investigation recorded 18 species distributed among 13 genera and 10 families, thereby providing one of the earliest inventories of corticolous lichens in Guyana. The study demonstrated that tree diversity and substrate availability were important drivers of species richness and composition. However, the relatively low number of species documented, compared with inventories conducted elsewhere in tropical regions, suggested that the observed diversity may reflect limitations associated with restricted sampling areas rather than the actual extent of lichen diversity. Furthermore, the concentration of these studies within anthropogenically modified landscapes limited the extent to which their findings could be generalized to natural ecosystems.

Recognizing the broader ecological, biotechnological, and pharmaceutical significance of lichens, Bhagarathi *et al.* (2022) [19] and Bhagarathi *et al.* (2023) [17] provide complementary perspectives on their importance, with the former focusing primarily on the ecological and environmental determinants of lichen diversity across the Neotropics, and the latter emphasizing their biological, chemical, ethnopharmacological, and pharmaceutical potential. Bhagarathi *et al.* (2022) [19] demonstrated that lichen communities are shaped by the interacting effects of climatic conditions, substrate characteristics, altitude, humidity, and host-tree properties, highlighting the importance of environmental heterogeneity and habitat characteristics in determining lichen distribution. In contrast, Bhagarathi *et al.* (2023) [17] shifted the focus from patterns of diversity and distribution to the functional and applied value of lichens, particularly their production of secondary metabolites with antimicrobial, antioxidant, anticancer, and anti-inflammatory properties. When considered together, these studies suggest that the ecological distribution of lichens and their potential biological value are interconnected: understanding where lichens occur, and the environmental conditions that support them, is fundamental to identifying and conserving species that may possess important biochemical properties. Both studies also highlight a broader limitation in tropical lichen research, namely the considerable disparity between the high biodiversity potential of tropical ecosystems and the relatively limited taxonomic, ecological, and biochemical knowledge available. This gap is especially pertinent to Guyana, where extensive forested landscapes remain poorly documented from a lichenological perspective. Consequently, the limited study of Guyanese lichens represents more than an inventory deficiency; it constrains understanding of their ecological roles while potentially overlooking species and compounds of biotechnological and pharmaceutical importance. Together, the findings of Bhagarathi *et al.* (2022) [19] and Bhagarathi *et al.* (2023) [17] therefore provide a strong rationale for integrated lichenological research in Guyana that combines taxonomic documentation with assessments of

environmental drivers, ecological functions, and potential bioactive properties.

Empirical investigations conducted by Bhagarathi *et al.* (2024a) [14] represented a significant advancement in the understanding of lichen host specificity within Guyanese coastal ecosystems. Their study of citrus species in the No. 63 Benab agroecosystem demonstrated that lichen assemblages varied considerably among host plants, indicating that bark texture, chemical composition, and microclimatic conditions influence species establishment and persistence. The authors further observed that certain hosts supported higher richness and abundance than others, reinforcing earlier conclusions proposed by Bacchus & Da Silva (2021) [11] regarding the importance of phorophyte identity in structuring lichen communities. In a complementary investigation, Bhagarathi *et al.* (2024b) [15] documented 30 species belonging to 23 genera and 15 families in coastal ecosystems at No. 63 Benab, representing one of the most comprehensive inventories of lichens undertaken in Guyana to date. The predominance of crustose forms observed in the study was consistent with patterns reported from other tropical environments and suggested adaptations to prevailing environmental conditions. Moreover, the substantially higher species richness recorded compared with previous urban surveys indicated that coastal agroecosystems may provide more heterogeneous habitats capable of supporting greater lichen diversity. Nevertheless, the study remained geographically confined to the coastal plain and therefore provided limited insight into inland forest ecosystems.

Recent studies have further expanded the understanding of host-associated variation among corticolous lichens. Bhagarathi *et al.* (2026b) [18] investigated lichen communities associated with *Azadirachta indica* across three sites in Berbice and demonstrated that species composition varied spatially despite the common host substrate. These findings highlighted the importance of local environmental conditions and suggested that factors operating beyond host identity contribute to community assembly. Similarly, Bhagarathi *et al.* (2026a) [16] examined corticolous lichens associated with *Cocos nucifera* across six villages in Berbice and recorded sixteen species distributed among eleven families. The moderate spatial heterogeneity observed among sites suggested that microhabitat variability, moisture availability, and bark characteristics influence community structure and species turnover. Collectively, these comparative studies indicate that both substrate specificity and environmental heterogeneity contribute to the distribution of corticolous lichens within Guyana.

Taken together, the available literature demonstrates that Guyana supports a diverse assemblage of lichens and that host-tree characteristics, substrate properties, and local environmental conditions are major determinants of species composition. Although lichen studies have been conducted in Guyana's forests and interior regions, research on lichens still is somewhat limited and geographically uneven. With much of the recent studies focused on accessible urban, suburban, and coastal or agroecosystem environments, there appears to be fewer reported studies that have examined lichen communities within inland forest ecosystems. This gap highlights the need for further investigation of lichen diversity and characteristics in less-studied interior locations such as Sophia Point.

Given that approximately 85% of Guyana is covered by forest and forms part of the Guiana Shield, one of the world's most important centres of biodiversity, the current knowledge base almost certainly underestimates the true extent of lichen diversity. Furthermore, the predominance of descriptive inventories and the absence of studies examining natural forest ecosystems highlight substantial gaps in understanding patterns of species distribution, community assembly, and ecological relationships. Consequently, comprehensive inventories in poorly studied inland regions, such as Region 10, are essential for establishing baseline data, improving taxonomic knowledge, and advancing conservation and biomonitoring efforts in Guyana.

Lichens in Rural Landscapes and the Need for Studies in Region 10

Studies from tropical regions have demonstrated that forest structure, humidity, bark characteristics, canopy openness and host-tree diversity strongly influence lichen communities [13, 39]. Secondary and undisturbed forests often harbour richer lichen assemblages than disturbed landscapes, emphasizing the importance of inventories in poorly studied regions [46].

The general aim of this study was to identify and assess the diversity and abundance of lichens at Sophia Point, Upper Demerara-Berbice, Guyana. Most investigations conducted in Guyana have focused on urban environments and coastal agroecosystems. Consequently, rural and inland ecosystems remain virtually unexplored. This represents a significant knowledge gap because environmental heterogeneity and reduced anthropogenic pressures in rural landscapes frequently support greater lichen diversity [45,55].

Upper Demerara-Berbice represents one such underexplored region. Sophia Point contains heterogeneous vegetation and environmental conditions that may support diverse lichen communities. However, this study is the first of its kind since no comprehensive inventory of lichens has been conducted in this locality. The absence of baseline information limits understanding of species distribution, host associations, and ecological functions.

Given that inventories constitute the foundation for ecological and conservation studies [82], documenting the diversity of lichens at Sophia Point is essential. Such information will contribute to understanding patterns of cryptogamic biodiversity within the Guiana Shield and provide baseline data for future ecological monitoring and conservation initiatives.

2. Methodology

Study Location

This research was conducted in the compound of the Sophia Point Rainforest Research Centre, Region 10, Guyana (Figure 1)

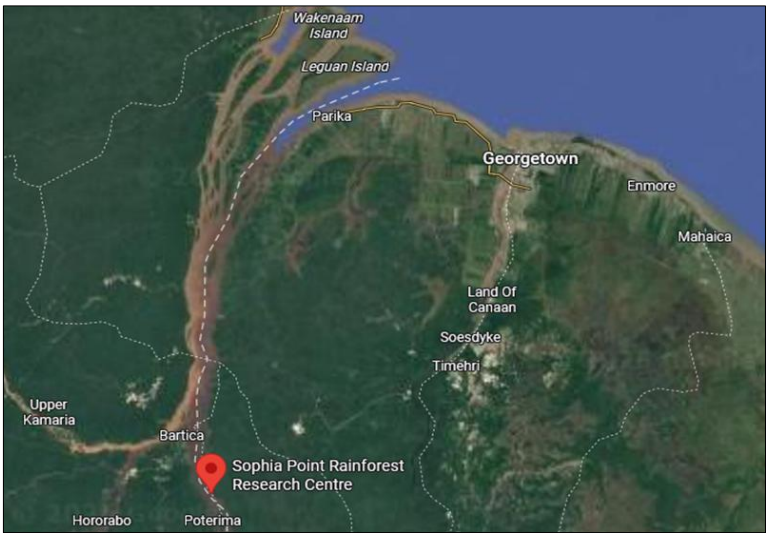

Fig 1: Location of Sophia Point Rainforest Research Centre

Experimental Design

A non-experimental observational design was employed to assess the presence and occurrence of lichens associated with selected woody plant hosts. Purposive sampling was used to identify suitable host trees based on predefined physical and ecological characteristics. This approach was informed by established lichenological methodologies emphasizing the use of suitable free-standing host trees and standardized observations of lichen communities on tree bark [7, 11, 12, 14, 15, 16, 18, 91]. Asta *et al.* (2002) [7] established the applicability of standardized lichen assessment on free-standing trees for documenting lichen diversity, abundance and environmental conditions.

Selection of Host Trees

At the designated study area, individual free-standing trees were examined for the presence of lichens. Host trees were selected purposively and included decorative, ornamental and agro-crop trees. Only healthy trees with relatively intact and undamaged bark were sampled. Trees exhibiting substantial bark damage, severe peeling, recent mechanical disturbance, burning or other conditions that could substantially modify the lichen-bearing substrate were excluded. Host-tree selection based on healthy and undamaged bark is consistent with previous lichen studies conducted in Guyana [11, 12, 14, 15, 16, 18].

Lichen Sampling

No transects or permanent sampling plots were established during the investigation. Instead, individual suitable trees encountered during field visits were treated as independent sampling units. On each selected tree, a standardized bark-sampling zone was established at approximately 5 ft (1.5 m) above ground level. This sampling height was selected to provide consistency among host trees and to permit safe and repeatable examination of the bark surface. Standardization of trunk sampling at approximately 150 cm has been employed in previous lichen investigations in Guyana [11, 12].

The bark surface at the standardized height was carefully examined for lichen presence. Observations were made around the accessible portion of the trunk, with attention given to differences in lichen occurrence among the major trunk aspects where these could be readily distinguished. Rock surfaces present close to the base of the trunk were also sampled. Each observed lichen morphotype was documented according to its growth form, abundance or frequency, reproductive structures and apparent percentage cover. Where individual thalli could be distinguished reliably, individual occurrences were counted; however, continuous crustose or leprose colonies were recorded using occurrence and/or estimated percentage cover because individual thalli could not always be delineated reliably.

Field Identification and Documentation

Preliminary identification was conducted *in situ* using a hand lens and based on morphological characteristics of the thallus and reproductive structures. Diagnostic features including thallus colour, growth form, degree of attachment to the substrate, lobation, branching, surface texture, apothecia, soredia and isidia were recorded. Identification was undertaken to species level where sufficient diagnostic characteristics were present and otherwise to genus or morphotype level. This approach follows the field-based morphological identification procedures described in previous Guyanese lichen investigations.

Photographs were taken of representative lichen colonies in their natural position on the host bark. Field observations were recorded on standardized datasheets together with information on host-tree identity, location, date of observation and specimen number.

Collection and Laboratory Identification of Lichen Specimens

Representative specimens that could not be identified in the field were carefully collected from the bark using a sterile scalpel. Only the minimum quantity required for identification was removed. Specimens were placed in labelled sterile plastic bags and transported to the laboratory for further examination.

Laboratory identification involved examination of morphological characteristics under magnification and consultation of appropriate lichenological identification keys and reference materials. Where necessary, chemical spot tests were undertaken by exposing the medulla through careful removal of a small portion of the cortex, followed by application of appropriate reagents. Resulting colour reactions were observed and recorded under magnification. This procedure is consistent with the morphological and chemical identification methodology used in prior research article and cited lichenological studies such as Kirika, 2012 [62]; Bhagarathi *et al*., 2024a [14], 2024b [15], 2026a [16], 2026b [18].

3. Results and Discussion

Morphological diversity and reproductive strategies of the lichen community

Table 1 presents the main characteristics of the 16 lichen taxa recorded during the survey. The taxa represented four principal growth-form categories: foliose, crustose, fruticose and crustose-leprose. Foliose lichens constituted the most conspicuous morphological group, represented by *Flavoparmelia caperata*, *F. soredians*, *Melanohalea exasperatula*, *Hypotrachyna laevigata*, *Dirinaria applanata*, *D. picta*, *Candelaria concolor*, *Xanthoria parietina* and *Collema furfuraceum*. Crustose taxa included *Candelariella reflexa*, *Anisomeridium biforme*, *Lecanora muralis* and *Lecanora conizaeoides*, whereas *Chrysothrix candelaris* and *Lepraria lobificans* exhibited characteristically leprose or powdery thalli. *Gymnoderma lineare* was recorded as a fruticose taxon in the present table.

The dominance of foliose forms is ecologically noteworthy. Foliose lichens possess flattened, leaf-like thalli that provide a relatively large surface area for light interception and gas and water exchange, while maintaining sufficient attachment to the bark substrate. In addition, foliose lichens frequently possess specialized vegetative propagules such as soredia and isidia. Bowler & Rundel (1975) [20] demonstrated that vegetative reproductive strategies are particularly well represented among foliose and fruticose lichens compared with crustose forms, and proposed that vegetative propagation may facilitate rapid colonization and persistence in suitable environments. This pattern is broadly consistent with the present assemblage, where most of the foliose species were recorded as producing either soredia or isidia.

The predominance of vegetative reproduction is also apparent from the reproductive-strategy of the 16 taxa. Soredia were recorded for *F. caperata*, *F. soredians*, *H. laevigata*, *D. picta*, *Candelariella reflexa*, *Chrysothrix candelaris* and *Lepraria lobificans*, while isidia were associated with *M. exasperatula*, *C. concolor* and *C. furfuraceum*. Apothecia were recorded for *X. parietina*, *Gymnoderma lineare*, *L. muralis* and *L. conizaeoides*, while pycnidia were reported for *D. applanata* and *A. biforme*. Thus, the assemblage demonstrates considerable reproductive diversity, but with a clear representation of vegetative propagule production.

Soredia and isidia are particularly important because they allow the fungal and photosynthetic partners of the lichen to be dispersed together. Soredia are small propagules consisting principally of fungal hyphae surrounding photobiont cells, whereas isidia are more structured outgrowths containing both symbiotic partners. Consequently, successful establishment does not require the newly dispersed fungal component to encounter a compatible photobiont independently. This is particularly advantageous for epiphytic organisms colonizing spatially discontinuous substrates such as tree bark [20, 26]. The occurrence of numerous sorediate and isidiate taxa in the present survey therefore suggests that vegetative dispersal may play an important role in maintaining lichen populations at the study site.

This finding is ecologically relevant because tree bark represents a heterogeneous and sometimes ephemeral habitat. Lichen colonization is influenced by bark chemistry, texture, moisture retention, pH, light exposure and microclimatic conditions. Previous work on corticolous lichens has shown that the characteristics of the host tree and its bark can strongly influence species distribution and community composition [64]. Similarly, Attanayaka & Wijeyaratne (2013) [8] demonstrated that corticolous lichen communities on *Mangifera indica* and other tropical tree species responded to environmental conditions and could be used to assess atmospheric pollution. More locally, Bacchus & Da Silva (2023) [12] recorded 18 corticolous lichen species belonging to 10 families and 13 genera in urban and suburban New Amsterdam, Berbice, demonstrating that corticolous lichen communities are already known to be diverse within the Berbice landscape. The present observations therefore contribute additional information on the morphological and reproductive diversity of bark-associated lichens in Guyana.

Table 1: Morphological and diagnostic characteristics of lichen taxa recorded during the survey

No.	Lichen species	Family	Common / descriptive name*	Thallus type	Identification characteristics based on the literature	References
1	*Flavoparmelia caperata*	Parmeliaceae	Common greenshield lichen	Foliose	Broad foliose lobes, pale green coloration and conspicuous vegetative propagules	[27, 92, 93, 94]
2	*Flavoparmelia soredians*	Parmeliaceae	Sorediate greenshield lichen	Foliose	Foliose thallus with conspicuous sorediate areas; repeatedly documented across all sites	[23, 27, 28, 29]
3	*Melanohalea exasperatula*	Parmeliaceae	Rough shield lichen	Foliose	Foliose thallus and numerous isidia; identified in the source study as an isidiate species	[75, 76, 77]
4	*Hypotrachyna laevigata*	Parmeliaceae	Smooth *Hypotrachyna* lichen	Foliose	Narrow foliose lobes and Parmeliaceae morphology	[30, 31]
5	*Dirinaria applanata*	Caliciaceae	Flat rosette lichen	Foliose	Flattened foliose thallus; soredia reported as reproductive structures	[58]
6	*Dirinaria picta*	Caliciaceae	Painted Dirinaria lichen	Foliose	Foliose thallus and sorediate reproductive structures	[58]
7	*Candelaria concolor*	Candelariaceae	Candleflame lichen	Foliose	Yellow foliose thallus with isidia	[50]
8	*Candelariella reflexa*	Candelariaceae	Powdery goldspeck lichen	Crustose	Crustose, sorediate, yellowish appearance	[72]
9	*Xanthoria parietina*	Teloschistaceae	Maritime sunburst / Yellow wall lichen	Foliose	Strong yellow-orange coloration and conspicuous apothecia	[32. 34]
10	*Gymnoderma lineare*	Cladoniaceae	Linear stalked lichen	Fruticose	Fruticose architecture and erect linear branches	[97]
11	*Chrysothrix candelaris*	Chrysotrichaceae	Powdery yellow lichen	Crustose-leprose	Characteristic powdery yellow crustose-leprose thallus and soredia	[33]
12	*Anisomeridium biforme*	Monoblastiaceae	Bark dot lichen	Crustose	Crustose thallus with minute dark reproductive structures	[49, 71]
13	*Collema furfuraceum*	Collemataceae	Brown jelly lichen	Foliose	Jelly-like foliose thallus, becoming darker and more translucent when wet	[51, 52]
14	*Lecanora muralis*	Lecanoraceae	Stonewall lichen	Crustose	Crustose / lobate margin and prominent apothecia	[59, 63,70]
15	*Lecanora conizaeoides*	Lecanoraceae	Smoky candle flame lichen	Crustose	Crustose thallus with numerous apothecia	[48, 53, 54]
16	*Lepraria lobificans*	Stereocaulaceae	Powdery dust lichen	Crustose-leprose	Powdery, granular appearance and lack of strongly differentiated lobes	[90]

Morphological and diagnostic characteristics of the recorded lichen taxa

1. ***Flavoparmelia caperata***

Flavoparmelia caperata is a foliose member of Parmeliaceae characterized by a relatively large, leafy thallus composed of broad, rounded and overlapping lobes. The thallus may form extensive patches on the bark and is generally loosely to moderately attached, becoming somewhat detached toward the centre as the thallus develops. The lobes are typically broad, wavy and rounded at their apices, with overlapping areas toward the centre of mature thalli. The upper surface is characteristically pale yellow-green to yellow-green, although it may appear grey-green in shaded conditions. The surface may also become distinctly wrinkled or corrugated, particularly toward the centre of older thalli [27, 92, 93, 94].

A prominent diagnostic characteristic of *F. caperata* is its pustular-sorediate surface. Soredia develop in pustule-like structures that may initially appear as small raised areas but can subsequently enlarge and coalesce into more extensive sorediate patches. The soredia themselves are relatively coarse and granular. The lower surface is generally dark brown to black, becoming somewhat brown toward the lobe apices [27, 92, 93]. The combination of a large yellow-green foliose thallus, broad lobes, corrugated surface and conspicuous coarse soredia gives *F. caperata* a distinctive overall appearance [27, 94].

2. ***Flavoparmelia soredians***

Flavoparmelia soredians, also belonging to Parmeliaceae, possesses a foliose, leaf-like thallus that generally forms relatively neat rosettes. The thallus is pale green to yellow-green or grey-green and consists of relatively narrow lobes that are more closely appressed than those of *F. caperata*. The lobes may become crowded toward the centre, producing a compact rosette-like appearance. The upper surface is characteristically silvery yellow-green, contributing substantially to its visual recognition [23, 28, 29].

The species is strongly associated with sorediate reproduction. Its soralia do not typically arise from large pustules but instead develop as relatively inconspicuous areas that gradually expand and fuse to produce finely sorediate regions over the thallus. The soredia are described as fine and farinose rather than coarse and granular. Consequently, *F. soredians* presents a relatively smooth, compact and finely powdery appearance [23, 28, 29] compared with the more extensively corrugated and coarsely sorediate *F. caperata* [27]. These characteristics correspond with the foliose, sorediate morphology documented for the species.

3. ***Melanohalea exasperatula***

Melanohalea exasperatula is a foliose Parmeliaceae species distinguished by an irregularly lobed thallus and numerous raised isidia. The thallus is relatively thin and closely attached toward the centre, while the marginal lobes may become raised, wavy and irregularly divided. The upper surface ranges from pale olive-green through dark olive-brown to brownish coloration and can become somewhat translucent when wet [75, 76, 77].

A particularly conspicuous feature is the abundance of isidia. These structures arise from the upper surface and initially appear as small, swollen projections. With development, they may become elongated, flattened, club-shaped or somewhat spoon-shaped and may eventually become divided or irregularly branched. Older isidia can become densely concentrated toward the central region of the thallus [75, 76, 77]. The combination of a dark greenish-brown foliose thallus and numerous raised isidia provides the principal morphological characteristics of this species.

4. ***Hypotrachyna laevigata***

Hypotrachyna laevigata is characterized by a foliose thallus consisting of relatively narrow, crowded and repeatedly branched lobes. The thallus may reach a considerable diameter and is generally loosely attached to the substrate. The lobes are linear to sublinear and may branch dichotomously, subdichotomously or irregularly. Their margins are usually entire but may occasionally become irregularly lobulate or finely dissected. The lobe apices may be truncate or pointed, and the lobe axils are commonly sinuous or V-shaped [30, 31].

The upper surface is typically glaucous, bluish-grey, grey-white or grey-green and may appear smooth, slightly pitted, shiny or matt. Maculation may be visible on the surface, while soralia occur mainly toward the terminal or subterminal portions of the lobes. The soredia are granular and may appear grey or darkened [30, 31]. The lower surface is predominantly black, with a brown marginal region and numerous branched rhizines. The narrow, divided or branched lobes and pale grey-green coloration provide important external characteristics, while its sorediate reproductive structures contribute to its diagnostic appearance.

5. ***Dirinaria applanata***

Dirinaria applanata is a foliose lichen characterized by a flattened, spreading and closely appressed thallus. Members of *Dirinaria* generally possess irregularly radiating lobes that may be discrete or confluent and lack marginal cilia. The upper surface is typically white-grey, grey or bluish-grey and may possess a pruinose appearance [58].

The thallus of *D. applanata* commonly forms relatively flat rosette-like patches on the substrate. Its lobes may become folded, longitudinally plicate or somewhat rugose, contributing to a textured rather than completely smooth appearance. Reproductive structures occur on the surface and may contribute to localized powdery areas. The overall combination of a flattened foliose thallus, radiating lobes and grey-green to bluish-grey colour gives *D. applanata* its characteristic appearance [58]. These characteristics correspond with the flat, spreading rosette morphology.

6. ***Dirinaria picta***

Dirinaria picta is another foliose member of the Caliciaceae characterized by a closely appressed, flattened thallus. The species generally develops radiating lobes that may overlap and become confluent toward the centre of the thallus. The upper surface is commonly grey, bluish-grey or grey-white and may exhibit a slightly pruinose appearance. The thallus is generally relatively flat, although the lobes can become somewhat irregular toward the margins [58].

The species is characterized by sorediate reproductive structures that develop on the thallus surface. These may occur as rounded or capitate soralia containing fine, farinose soredia. The combination of a flattened foliose thallus, radiating lobes, pale grey-green to bluish-grey coloration and conspicuous sorediate regions corresponds closely with the morphology recorded [58].

7. *Candelaria concolor*

Candelaria concolor is a relatively small foliose lichen with a distinctive yellow to yellow-green colour. Its thallus consists of numerous small, narrow and finely divided lobes that may form small rounded cushions or expand irregularly into broader patches. The lobes are generally flattened, approximately linear to slightly fan-shaped, and may overlap or become irregularly distributed across the substrate. The upper surface ranges from bright yellowish-green to chrome yellow, whereas the lower surface is considerably paler [50].

The margins of the lobes may become crenulate, granular, isidiate or coarsely sorediate. Isidia may therefore contribute substantially to the granular appearance of the thallus. The combination of small size, finely divided lobes and bright yellow-green coloration is particularly characteristic. The presence of isidia further contributes to the diagnostic appearance of this species [50].

8. *Candelariella reflexa*

Candelariella reflexa represents a markedly different growth form from the larger foliose taxa because its thallus is crustose and closely associated with the bark surface. The thallus is composed of small granular structures that are generally greenish to yellow-green in shaded conditions and become more yellow under stronger illumination. Minute squamule-like structures may also be present, producing a granular to slightly uneven surface [72].

Abundant bright yellow soredia may cover the granular thallus, giving the lichen a distinctly powdery or fluffy appearance. In some specimens, the soredia can become sufficiently abundant to produce an almost continuous leprose or farinose crust [72]. The combination of a thin crustose thallus, yellow-green coloration, granular texture and conspicuous yellow soredia corresponds with the morphology.

9. *Xanthoria parietina*

Xanthoria parietina is one of the most visually conspicuous taxa because of its bright yellow-orange to orange coloration. It is a foliose lichen with broad, rounded and slightly wrinkled overlapping lobes. The upper surface is usually bright yellow to orange but may become greyish in shaded environments. The lobes form relatively broad patches and overlap toward the central portion of the thallus [32. 34].

The lower surface is generally pale or white, contrasting strongly with the brightly coloured upper surface. Numerous orange apothecia are commonly present, particularly toward the centre of mature thalli. These apothecia possess a paler margin surrounding the orange disc, creating highly conspicuous reproductive structures [32, 34]. Consequently, the combination of broad foliose lobes, bright yellow-orange coloration and numerous orange apothecia provides a distinctive morphological profile for *X. parietina*.

10. *Gymnoderma lineare*

Gymnoderma lineare is characterized by a three-dimensional growth form that differs substantially from the flattened foliose and closely attached crustose lichens. The thallus is erect and narrow, producing a linear or stalked appearance. Its branches are relatively slender and project outward from the substrate, giving the organism a distinctly upright architecture rather than a flat, leaf-like form [97].

The colour is generally pale grey-green to grey, allowing the thallus to contrast moderately with darker bark or rock surfaces. The erect branching structure provides a characteristic fruticose habit, in which much of the thallus projects into the surrounding air rather than remaining closely attached to the substrate. Reproductive structures may occur toward the terminal or upper portions of the branches. The three-dimensional, narrow and upright architecture described therefore represents the principal morphological feature of this taxon [97].

11. *Chrysothrix candelaris*

Chrysothrix candelaris is a crustose-leprose lichen with a highly distinctive powdery appearance. Unlike foliose lichens, it lacks strongly differentiated leafy lobes and instead develops as a thin, loosely organized superficial layer. The thallus is typically bright yellow to yellow-green, making it one of the most visually distinctive crustose taxa in the survey [33].

The surface is characteristically granular and powdery because of the abundance of small vegetative propagules. The thallus may appear almost dust-like when viewed at close range, with poorly differentiated boundaries between the lichen and the substrate. The yellow coloration combined with the fine powdery texture and sorediate surface provides the principal morphological characteristics of *C. candelaris* [33]. Its appearance contrasts strongly with the more structured lobes of *Flavoparmelia*, *Dirinaria* and *Xanthoria*.

12. *Anisomeridium biforme*

Anisomeridium biforme is a crustose lichen with a very thin, closely attached thallus. The thallus is generally whitish, dirty white, pale grey or pale grey-green and may appear smooth, cracked or finely fissured. In some conditions, the thallus may become more greenish, particularly when young or moist. A thin, diffuse darker prothalline margin may sometimes surround the thallus [49, 71].

The reproductive structures are small and dark and are embedded within or only slightly protruding from the thallus. Perithecia may appear as small black dots, while pycnidia can also occur across the thallus. These structures are considerably smaller and less conspicuous than the apothecia of large foliose lichens. The combination of a thin pale crustose thallus and minute dark reproductive structures provides the principal visual characteristics of *A. biforme* [49, 71].

13. *Collema furfuraceum*

Collema furfuraceum possesses a distinctive foliose, gelatinous or jelly-like thallus. The thallus is thin, membrane-like and closely attached to the substrate, with rounded or extended lobes that may overlap. When dry, the thallus is dark olive-green, brownish or nearly black, whereas hydration causes it to become softer, darker and more translucent [51, 52].

The surface is characterized by conspicuous ridges that radiate across the lobes. Isidia develop abundantly along these ridges and are initially cylindrical or simple but may become branched and coralloid with age. The hydrated appearance is particularly distinctive because the thallus becomes gelatinous and translucent, differentiating it from the more rigid foliose lichens. The dark brown to olive-brown coloration, gelatinous texture and abundant isidia therefore constitute the principal morphological characteristics of *C. furfuraceum* [51, 52].

14. *Lecanora muralis*

Lecanora muralis has a crustose to placodioid growth form and generally develops circular or rosette-like patches. The thallus is closely attached to the substrate and may possess a greyish-green to pale greenish-yellow upper surface. The central region is more strongly crustose or areolate, while the margins develop flattened, radiating lobes. The surface can appear somewhat glossy or waxy, and the marginal portions may become slightly pruinose [59, 63,70].

Apothecia are generally conspicuous and may occur toward the centre or between the marginal lobes. They are sessile and possess a thalline margin, while the discs range from yellowish-brown to orange-brown. The combination of a closely attached crustose centre, radiating marginal lobes and conspicuous disc-like apothecia produces the characteristic placodioid appearance of the species [63, 70]. This morphology corresponds with the crustose-to-lobate-crustose form and prominent apothecia.

15. *Lecanora conizaeoides*

Lecanora conizaeoides is a crustose lichen characterized by a relatively thick, coarsely granular and generally continuous thallus. The thallus is typically grey-green and closely attached to the substrate. One of its most prominent surface characteristics is the development of abundant grey-green soredia across much of the thallus, which can give the species a distinctly powdery or granular appearance [48, 53, 54].

Apothecia may also be present and are generally sessile, with pale green-grey to grey-brown discs. The apothecial margins may be crenulate, granular or sorediate, and the discs may be flat or slightly concave. Consequently, the species can exhibit a combination of a granular crustose thallus, powdery sorediate areas and discrete apothecia. The pale grey to grey-green coloration and numerous reproductive structures are consistent with this morphology [48, 53, 54].

16. *Lepraria lobificans*

Lepraria lobificans is a crustose-leprose lichen characterized by a soft, diffuse and powdery thallus. Unlike the strongly differentiated lobes of foliose lichens, its thallus is poorly organized and has a cottony or woolly appearance. The colour ranges from green to light grey, with a prominent pale medullary component visible beneath the powdery surface [90].

The thallus margin is generally diffuse rather than sharply delimited, although small sublobes may occasionally develop. Soredia are loosely packed and vary in size, with projecting fungal hyphae contributing to the soft, woolly texture. The species may therefore form diffuse patches across the bark surface and can occupy small cracks and crevices between other organisms [90]. Its pale grey-green to bluish-grey coloration, diffuse powdery structure and absence of strongly differentiated foliose lobes provide the principal morphological characteristics of *L. lobificans* [90].

17. Overall morphological pattern

The taxa presented in Table 1 demonstrate considerable variation in external thallus morphology, ranging from broad foliose forms to thin crustose and highly powdery leprose forms. The foliose taxa generally possessed conspicuous lobes and relatively differentiated thallus architecture, whereas the crustose taxa remained closely attached to the bark surface. The leprose species, particularly *Chrysothrix candelaris* and *Lepraria lobificans*, exhibited the least differentiated thallus structure, appearing primarily as powdery or granular coatings.

Colour was also an important characteristic. Green and grey-green shades predominated among many of the Parmeliaceae and Caliciaceae, while yellow and yellow-green coloration was particularly evident in *Candelaria concolor*, *Candelariella reflexa* and *Chrysothrix candelaris*. The bright yellow-orange thallus of *Xanthoria parietina* was especially distinctive. Such differences in colour, thallus architecture, surface texture and reproductive structures provide a combination of characters that can be used to distinguish the recorded taxa during morphological surveys.

Overall, the taxa recorded in Table 1 represent a broad spectrum of lichen growth forms and external morphologies. Their variation in thallus shape, attachment, colour, surface texture and reproductive structures illustrates the structural diversity of the lichen community associated with the sampled trees.

Overall interpretation of reproductive strategies

An emerging pattern is the strong representation of vegetative reproduction. Soredia and isidia were associated with most of the taxa, while comparatively fewer taxa were recorded primarily through apothecia or pycnidia. This pattern agrees with the broader observation of Bowler & Rundel (1975) [20] that foliose and fruticose lichens have a greater representation of vegetative reproductive mechanisms than crustose lichens.

The ecological significance of this pattern is substantial. Sexual reproduction through apothecia allows genetic recombination and dispersal of fungal spores, but an ascospore must subsequently encounter a suitable photobiont before a new lichen thallus can become established. Vegetative propagules avoid this limitation because they transport the fungal and photosynthetic partners together [26]. In a fragmented habitat such as tree bark, this can provide a major colonization advantage.

Because of the small size and lightweight structure of the soredia, it is easy for them to be dispersed by wind and rain and as such this factor may contribute to the local and, under

favourable conditions, wider dispersal of lichens. In comparison, isidia are usually larger and structurally more robust, which results in shorter dispersal distances and so make them important for local colonization and expansion around established thalli [5, 6].

Thus, the predominance of these propagules suggests that many species in the surveyed community possess reproductive mechanisms capable of rapid establishment on suitable bark surfaces.

Nevertheless, the occurrence of apothecia in *Xanthoria parietina*, *Lecanora muralis* and *Lecanora conizaeoides* demonstrates that sexual reproduction remains an important component of the community. Sexual reproduction is especially important from an evolutionary perspective because it generates genetic variation, which may improve the ability of populations to respond to changing environmental conditions. Consequently, the combination of vegetative and sexual reproduction observed in the study reflects multiple ecological and evolutionary strategies rather than a single dominant reproductive pathway.

Relationship between morphology and lichen habitat

The morphological diversity can also be interpreted in relation to the physical characteristics of the barks of trees. Lichens experience considerable spatial variation in moisture, irradiance, temperature, bark pH, roughness and nutrient availability. The tree therefore functions not simply as a passive substrate but as a heterogeneous habitat capable of supporting species with different ecological requirements.

Foliose species such as *Flavoparmelia*, *Hypotrachyna* and *Dirinaria* possess relatively large surface areas and can exploit exposed bark where sufficient light is available. Crustose species such as *Anisomeridium* and *Lecanora* can remain closely attached to the substrate and occupy microsites where a loosely attached foliose thallus would be less successful. Leprose species such as *Chrysothrix* and *Lepraria* represent an even more extreme adaptation to superficial colonization of bark.

The presence of these contrasting growth forms on the same host species suggests that the bark surface is partitioned into numerous microhabitats. Similar ecological differentiation has been documented in tropical lichen communities. Attanayaka & Wijeyaratne (2013) [8], for example, demonstrated that lichen diversity on tropical woody trees, was associated with environmental variables such as bark characteristics, light exposure and atmospheric pollution. Likewise, research from tropical forests has demonstrated considerable variation in lichen assemblages among forest types and environmental conditions [85]. The high morphological diversity observed suggests that the bark of woody plants provide a range of microsites suitable for lichens with different attachment mechanisms, thallus architectures and reproductive strategies.

Comparison with previous studies in Guyana

The results presented are consistent with evidence that there is a diverse corticolous lichen flora in Guyana. Bacchus & Da Silva (2023) [12], in their study of corticolous lichens in urban and suburban New Amsterdam, Berbice, recorded 14,978 individual lichens representing 10 families, 13 genera and 18 species. Their study included several taxa also represented in the present table, including *Hypotrachyna laevigata* and *Dirinaria applanata*. Their finding that *D. applanata* was restricted to *Cocos nucifera* in their sampling sites is particularly interesting when compared with its occurrence on *Mangifera indica* in the present study.

The comparison suggests that host-tree relationships may influence lichen distribution but may not necessarily indicate strict host specificity. A species recorded on one host in a particular survey may occur on additional tree species under different environmental conditions. Consequently, the occurrence of *D. applanata* and other taxa on woody plants contributes to a broader understanding of substrate use by Guyanese corticolous lichens. The present study also complements tropical studies from outside Guyana. Attanayaka & Wijeyaratne (2013) [8] used *Mangifera indica*, *Cocos nucifera* and *Artocarpus heterophyllus* as host trees in Sri Lanka and demonstrated that corticolous lichen communities could be related to atmospheric conditions and pollution.

This is particularly relevant because it demonstrates that woody plants can serve as an important host for lichen biodiversity assessments in tropical environments. It indicates that lichen diversity on woody plants can serve as a bioindicator of environmental conditions and ecosystem quality. Because lichens are highly sensitive to changes in air quality, humidity, light availability, substrate characteristics, and other ecological disturbances, the presence, richness, composition, and abundance of lichen species on tree bark can reflect the prevailing environmental conditions of a tropical habitat. Therefore, woody plants act as important substrates that support lichen communities whose diversity patterns may provide indirect evidence of habitat integrity, microclimatic stability, and the level of environmental disturbance. A high diversity of lichen species on suitable woody hosts may consequently indicate favourable and relatively stable ecological conditions, whereas changes or reductions in lichen diversity may signal alterations in environmental quality [11, 12, 14, 15, 16, 17, 18, 19].

Overall, the morphological diversity documented in this study demonstrates that the woody plant bark community supports lichens exhibiting substantial variation in thallus architecture and reproductive strategy. The predominance of foliose and vegetatively reproducing taxa suggests that efficient local dispersal and rapid establishment may be important ecological strategies within the community. At the same time, the occurrence of crustose, leprose and sexually reproducing taxa indicates that the bark habitat provides a mosaic of ecological niches capable of supporting organisms with markedly different life-history strategies. The results therefore provide an important baseline for understanding lichen diversity in Berbice, Guyana and support previous findings that tropical tree bark can sustain complex and environmentally responsive lichen communities [8, 12].

Table 2: Chemical spot-test characteristics used for identification of lichens

No.	Species	Family	Physical thallus colour	K Test - KOH	C Test - Hypochlorite	KC Test - KOH + C	P Test - p-phenylenediamine	Diagnostic identification	Method
1	*Flavoparmelia caperata*	Parmeliaceae	Yellow-green to pale green	No reaction to dirty-yellow	No reaction	Weak red reaction	Orange-red	Foliose, pale green thallus with soredia; K−/dirty yellow and P+ orange-red	[57, 83]
2	*Flavoparmelia soredians*	Parmeliaceae	Pale green to yellow-green	Yellow → red	No reaction	Red	Orange	K+ yellow → red, KC+ red and P+ orange; sorediate foliose thallus	[57, 78]
3	*Melanohalea exasperatula*	Parmeliaceae	Dark greenish-brown to brown-grey	No reaction	No reaction	No reaction	No reaction	Predominantly negative chemistry; foliose thallus with conspicuous isidia	[44, 47]
4	*Hypotrachyna laevigata*	Parmeliaceae	Pale grey-green	No reaction	No reaction	No reaction	No reaction	Narrowly divided foliose lobes; predominantly negative spot reactions	[56, 83]
5	*Dirinaria applanata*	Caliciaceae	Grey-green to bluish-grey	Yellow	No reaction	No reaction	Yellow	K+ yellow and P+ yellow; flattened foliose thallus with pycnidia	[83]
6	*Dirinaria picta*	Caliciaceae	Pale grey-green to bluish-grey	Yellow	No reaction	No reaction	Yellow	K+ yellow and P+ yellow; sorediate foliose thallus	[10, 83]
7	*Candelaria concolor*	Candelariaceae	Yellow to yellow-green	No reaction/faint pink	No reaction	No reaction	No reaction	Yellow foliose thallus with isidia; generally negative chemistry	[37, 99]
8	*Candelariella reflexa*	Candelariaceae	Yellow-green to yellowish	No reaction	No reaction	No reaction	No reaction	Yellowish crustose-sorediate thallus; predominantly negative chemistry	[37, 100]
9	*Xanthoria parietina*	Teloschistaceae	Bright yellow-orange to orange	Red → purple/crimson	No reaction	No reaction	No reaction	Strong K+ red-purple reaction combined with yellow-orange foliose thallus and apothecia	[83, 95]
10	*Gymnoderma lineare*	Cladoniaceae	Pale grey-green to grey	Variable; specimen confirmation required	Variable; specimen confirmation required	Variable	Variable	Erect three-dimensional/fruticose thallus with apothecia; chemistry used as supplementary evidence	[1, 4]
11	*Chrysothrix candelaris*	Chrysotrichaceae	Bright yellow to yellow-green	Negative to orange; may darken	No reaction	No reaction	Negative to orange	Characteristic yellow powdery/leprose thallus and sorediate reproduction	[67, 83]
12	*Anisomeridium biforme*	Monoblastiaceae	White-grey to pale grey	No reaction	No reaction	No reaction	No reaction	K−, C−, KC−, P−; thin crustose thallus with minute reproductive structures	[84]
13	*Collema furfuraceum*	Collemataceae	Dark brown to olive-brown	No reaction	No reaction	No reaction	No reaction	Negative chemistry; gelatinous foliose thallus and isidia diagnostic	[38, 43]
14	*Lecanora muralis*	Lecanoraceae	Grey-green to pale green-grey	No/weak yellow	No reaction	Yellow/gold possible	No reaction	Crustose to lobate-crustose thallus with apothecia; chemistry supplementary	[37, 80]
15	*Lecanora conizaeoides*	Lecanoraceae	Pale grey to grey-green	No strong reaction	No reaction	No reaction	Variable/weak	Thin crustose thallus with conspicuous apothecia; chemistry generally weak	[66, 88]
16	*Lepraria lobificans*	Stereocaulaceae	Pale grey-green to bluish-green	Negative/weak yellow	No reaction	No reaction	Orange	Powdery leprose thallus; C−, KC− and P+ orange support identification	[69, 83]

Chemical spot-test characteristics used for identification of lichens

Chemical spot tests are particularly useful because they provide a rapid qualitative indication of particular classes of lichen substances through visible colour reactions. The principal tests used in the present study were K (potassium hydroxide, KOH), C (hypochlorite), KC (KOH followed by hypochlorite) and P (p-phenylenediamine). These tests are conventionally recorded as positive (+) when a characteristic colour reaction occurs and negative (-) when no visible reaction is produced [87].

The chemical spot-test results presented in Table 2 demonstrate that secondary chemistry provided an important complementary tool for distinguishing the lichen taxa recorded during the survey. Lichen identification traditionally combines macromorphological characters, reproductive structures, anatomical features and secondary chemistry because closely related or morphologically similar lichens may differ in their production of characteristic secondary metabolites [37, 87].

The reactions recorded in Table 2 ranged from strongly diagnostic colour changes, such as the red-to-purple K reaction of *Xanthoria parietina*, to completely negative reactions across all four tests in several species. Such variation reflects differences in the type, concentration and distribution of secondary metabolites within the thallus. Importantly, a negative reaction does not indicate that a lichen contains no chemical compounds; rather, it generally indicates that the compounds present either do not react visibly with the reagent used or are present at concentrations insufficient to produce a readily observable reaction. Spot tests therefore provide qualitative chemical fingerprints rather than complete chemical profiles [37, 87].

Significance of the K, C, KC and P tests

The K test uses potassium hydroxide, usually approximately 10%, to detect particular secondary metabolites through characteristic colour changes. Yellow reactions, yellow-to-red reactions and red-to-purple reactions can provide useful evidence of different classes of lichen substances. For example, KOH commonly produces a characteristic reddish-purple reaction in lichens containing anthraquinone pigments, including *Xanthoria parietina* [87].

The C test uses a hypochlorite reagent as an oxidizing agent. Positive reactions may be pink, red or orange, although reactions can be rapid and sometimes transient. Consequently, the absence of a visible reaction should be interpreted carefully, particularly when the reaction is weak or short-lived. The British Lichen Society emphasizes that fresh C reagent is important because old hypochlorite solutions can produce false-negative results [22].

The KC test combines KOH and hypochlorite sequentially. The combined reaction may reveal chemical characteristics that are not apparent when either reagent is used individually. A KC reaction can therefore provide additional discriminatory

information, particularly among species with similar K and C reactions [87].

The P test uses p-phenylenediamine and can produce yellow, orange or red reactions depending on the compounds present. P reactions are especially useful in separating species that may otherwise have very similar thallus morphology and colour. Consequently, the inclusion of the P test in the present investigation strengthened the chemical component of species identification [87].

Chemical characteristics of individual lichen taxa

1. ***Flavoparmelia caperata***

As shown in Table 2, *Flavoparmelia caperata* exhibited no clear K reaction, although a dirty-yellow change was observed, no reaction with C, a weak red reaction with KC and a distinct orange-red reaction with P. This chemical profile complements its pale yellow-green foliose morphology and sorediate thallus. Previous descriptions of *F. caperata* similarly report a K-negative or weak dirty-yellow medullary reaction, a KC reaction that may become reddish, and a P-positive orange-red reaction [92, 93, 94].

The P+ orange-red reaction is therefore particularly useful as a supplementary diagnostic characteristic. The combination of a pale green foliose thallus and P+ orange-red chemistry provides a stronger identification profile than morphology alone. The weak KC reaction recorded in Table 2 may also indicate the presence of compounds capable of producing a reaction only after sequential treatment with the two reagents. The relatively weak or absent response to K and C individually illustrates why several reagents are often used together rather than relying on a single chemical test.

2. ***Flavoparmelia soredians***

Flavoparmelia soredians displayed a much more pronounced chemical response than *F. caperata*. KOH produced a yellow reaction that developed into red, KC produced a red reaction, and P produced an orange reaction, while C alone produced no reaction. This profile is strongly consistent with published descriptions of the species. The British Lichen Society reports a cortex that is K-, with the medulla producing K+ yellow followed by red, KC+ red and P+ orange reactions. The major substance associated with this profile is salazinic acid [23, 28, 29].

The K+ yellow → red reaction is particularly useful because the colour transition indicates that the chemical constituents are undergoing a visible reaction over time rather than producing an instantaneous colour change. The agreement between the K, KC and P reactions recorded in Table 2 and previously documented chemistry demonstrates the value of combining multiple spot tests. In this species, the chemical profile complements the pale green/yellow-green sorediate foliose thallus and provides an additional character for distinguishing it from morphologically similar *Flavoparmelia* taxa.

3. ***Melanohalea exasperatula***

All four chemical tests recorded in Table 2 were negative for *Melanohalea exasperatula*. The species therefore exhibited a predominantly negative spot-test profile, with K-, C-, KC- and P- reactions. This result is consistent with previous descriptions of the species, which report negative medullary reactions to K, C, KC and P [75, 76, 77].

The negative chemical profile is nevertheless informative. In combination with the dark olive-brown foliose thallus and conspicuous isidia, the absence of visible chemical reactions contributes to the species' overall identification profile. Thus, a negative result should not be regarded as a failure of the chemical test; rather, the absence of a reaction constitutes a character that can help distinguish taxa. The result also illustrates that morphological characters such as isidial structure may be more prominent than chemical reactions in some species.

4. ***Hypotrachyna laevigata***

Hypotrachyna laevigata produced no visible reaction in any of the four chemical tests recorded in Table 2. Thus, its profile was K-, C-, KC- and P-. The chemical results were interpreted together with the narrow, repeatedly divided foliose lobes and pale grey-green thallus. The predominantly negative chemistry provides a simple chemical background against which the morphological characters become particularly important.

Negative spot reactions are not unusual in lichens because secondary metabolites vary substantially among taxa, and not all metabolites produce a visible response with standard field reagents [87]. In the case of *H. laevigata*, therefore, the absence of visible colour changes can be regarded as part of its diagnostic chemical profile rather than evidence of an absence of secondary chemistry.

5. ***Dirinaria applanata***

As indicated in Table 2, *Dirinaria applanata* produced a yellow reaction with KOH and P, while C and KC produced no visible reaction. This K+ yellow/P+ yellow profile is consistent with published chemical descriptions of the species. Elix's treatment of *D. applanata* records K+ yellow, C-, KC- and P+ yellow reactions and identifies atranorin and divaricatic acid among its principal lichen substances [9].

The chemical results therefore complement the grey-green to bluish-grey flattened thallus described in Table 2. The yellow K reaction is particularly useful because it provides a visible chemical character that is not necessarily apparent from the external appearance of the lichen. The P+ yellow reaction further supports the chemical differentiation of *D. applanata* within the recorded Caliciaceae.

6. ***Dirinaria picta***

Dirinaria picta showed a chemical pattern essentially similar to *D. applanata*, with K+ yellow and P+ yellow reactions and no visible C or KC reaction. Previous chemical studies of *D. picta* report exactly this general profile: K+ yellow, C-, KC- and P+ yellow, with atranorin and divaricatic acid identified among its secondary metabolites [58].

The similarity in chemistry between the two *Dirinaria* species is noteworthy because they also possess broadly similar grey to bluish-grey foliose thalli. This demonstrates that chemical tests are most effective when interpreted alongside morphology. In *D. picta*, the K+ yellow and P+ yellow reactions complement the flattened, sorediate thallus and provide additional evidence for identification.

7. *Candelaria concolor*

Candelaria concolor showed predominantly negative reactions in Table 2, with K recorded as no reaction to faint pink and C, KC and P all negative. This pattern is consistent with published chemical descriptions of the species. The British Lichen Society reports *C. concolor* as K-, although a dirty-brown or deeper yellow response can occasionally occur, while other treatments report C-, KC- and P- [21, 73].

The chemical profile is therefore complementary to the species' highly distinctive yellow to yellow-green foliose thallus. The K-negative characteristic is particularly useful when distinguishing *C. concolor* from yellow-orange lichens that produce strong K-positive reactions. Thus, the predominantly negative chemistry recorded in Table 2 is a meaningful component of its identification.

8. *Candelariella reflexa*

All four spot tests produced no visible reaction for *Candelariella reflexa*, resulting in a K-, C-, KC- and P- profile. The absence of colour reactions can be particularly useful when combined with its yellow-green crustose and sorediate morphology. In this case, the physical colour of the thallus provides a prominent field character, while the negative chemistry provides supplementary information.

The result illustrates an important principle of lichen chemistry: not every species possesses secondary metabolites that produce a readily visible reaction with standard K, C, KC and P reagents. Consequently, negative reactions can contribute to a species-specific chemical profile even when no diagnostic colour change is produced [87]. The combination of yellowish coloration, crustose growth and predominantly negative chemistry therefore forms the identification profile recorded in Table 2.

9. *Xanthoria parietina*

Among the taxa examined, *Xanthoria parietina* produced one of the strongest and most visually distinctive chemical reactions. As shown in Table 2, KOH produced a red reaction that subsequently developed toward purple/crimson, while C, KC and P produced no reaction. This strong K+ red-purple response is characteristic of *Xanthoria* and is widely used in lichen identification [32, 87].

The chemical response is particularly valuable because it complements the bright yellow-orange physical appearance of the thallus. The combination of bright yellow-orange foliose morphology, conspicuous apothecia and strong K+ red-purple chemistry provides a highly distinctive identification profile. The reaction is associated with anthraquinone pigments, which are responsible for the characteristic yellow-orange coloration of many Teloschistaceae lichens [87].

10. *Gymnoderma lineare*

The chemical reactions recorded for *Gymnoderma lineare* in Table 2 were variable for K, C, KC and P. The chemistry was therefore used as supplementary information alongside the conspicuous erect, three-dimensional thallus and apothecia. The variable nature of spot reactions among individual specimens can reflect differences in secondary metabolite expression, concentration or distribution within the thallus.

For taxa with distinctive gross morphology, chemical tests can function primarily as corroborative evidence rather than the sole basis for identification. This is consistent with the general principle of lichen identification, where morphology, anatomy and chemistry are interpreted together rather than independently [37, 87].

11. *Chrysothrix candelaris*

Chrysothrix candelaris produced a variable K response ranging from negative to orange with darkening, no C or KC reaction and a negative-to-orange P response. This pattern is consistent with documented chemistry for the species, for which K and P reactions may produce orange colouration, sometimes becoming darker, while C and KC are generally negative [9].

The chemical characteristics are particularly interesting when considered alongside the striking yellow colour of the thallus. The species contains yellow pigments such as calycin, which contribute to its vivid appearance and can also participate in characteristic chemical reactions [9]. The chemical results therefore complement its bright yellow, powdery-leprose morphology and sorediate structure.

12. *Anisomeridium biforme*

Anisomeridium biforme produced no visible reaction in any of the four tests, resulting in a K-, C-, KC- and P- profile. The lack of colour reactions is consistent with the use of morphology as an important identification feature in this taxon. Its thin white-grey crustose thallus and minute reproductive structures are therefore complemented by a predominantly chemically inactive spot-test profile.

The negative results demonstrate that chemical testing does not necessarily generate a conspicuous colour response for every lichen. As described by Orange *et al.* (2001) [87], spot tests detect particular chemical constituents or chemical groups rather than all substances present in a lichen. Consequently, a lichen can contain secondary metabolites that do not react visibly with the standard K, C, KC or P reagents.

13. *Collema furfuraceum*

All four spot tests were negative for *Collema furfuraceum*, producing a K-, C-, KC- and P- profile in Table 2. Previous investigations similarly describe *C. furfuraceum* as having little or no detectable chemistry by conventional spot testing. For example, lichen identification resources report no substances detectable through standard spot tests or thin-layer chromatography for related *Collema* material, while recent descriptions of *C. furfuraceum* emphasize its olive-brown, ridged and isidiate morphology as the major diagnostic characters [74]. The lack of visible chemical reactions therefore places greater diagnostic emphasis on the species' gelatinous thallus, dark olive-brown colour, ridged surface and characteristic isidia. The result illustrates that some lichen taxa can be effectively distinguished using morphological and anatomical features even when conventional chemical spot tests provide little additional differentiation.

14. *Lecanora muralis*

Lecanora muralis produced either no reaction or a weak yellow reaction with K, no reaction with C, a yellow/gold

reaction with KC and no reaction with P. These results indicate relatively weak chemical responses compared with strongly reactive species such as *Xanthoria parietina*. Published descriptions also demonstrate that *L. muralis* can exhibit limited spot-test reactions; one treatment reports K-, C- and Pd- chemistry, while other records a pale-yellow KC reaction [9, 24].

The weak chemical profile therefore complements the morphological characters of the grey-green crustose to lobate-crustose thallus and conspicuous apothecia. In this species, the chemical tests provide supplementary rather than strongly contrasting colour characters, illustrating the importance of combining chemical reactions with thallus morphology and reproductive structures.

15. *Lecanora conizaeoides*

Lecanora conizaeoides exhibited relatively weak chemistry in Table 2. The K reaction was recorded as showing no strong reaction, C and KC were negative, and P was variable or weak. Published descriptions indicate that the species can produce a weak yellow K reaction and an orange to deep-red P reaction, with C negative [48, 53, 54].

The generally weak reaction profile is therefore consistent with the observation that spot-test responses may be subtle in some lichen species. In *L. conizaeoides*, the chemical results are interpreted alongside the pale grey to grey-green crustose thallus and conspicuous apothecia. The P reaction, even when weak, can provide useful supplementary evidence when morphological characteristics are considered simultaneously.

16. *Lepraria lobificans*

Lepraria lobificans showed negative to weak yellow K chemistry, no reaction with C or KC and an orange P reaction. This profile is particularly informative because *Lepraria* species often possess poorly differentiated, powdery thalli that make morphological separation difficult. Previous work has emphasized the importance of chemistry in distinguishing morphologically similar *Lepraria* taxa [68].

Published descriptions of *L. lobificans* report K+ yellow, C-, KC- and P+ yellow-orange reactions and identify compounds such as atranorin, zeorin and members of the stictic-acid complex [90]. The orange P reaction recorded in Table 2 therefore provides a useful chemical characteristic alongside the pale grey-green to bluish-green powdery thallus.

Interpretation of negative chemical reactions

A substantial proportion of the taxa in Table 2 produced no visible reaction with one or more of the chemical reagents. This is an expected feature of lichen spot testing and should not be interpreted simply as evidence that the lichen contains no secondary metabolites. Lichens produce a highly diverse array of secondary compounds, including depsides, depsidones, dibenzofurans, anthraquinones, xanthones, terpenoids and other substances, but these compounds do not all react visibly with KOH, hypochlorite or p-phenylenediamine [37, 87].

There are several biological reasons why a species may show no visible reaction. First, the species may lack metabolites that are reactive with the particular reagent being applied. Second, a metabolite may be present at a concentration below the level required to produce an observable colour response. Third, secondary metabolites may be concentrated primarily in particular anatomical regions, such as the cortex or medulla, meaning that testing a different portion of the thallus may produce a weak or negative result. This is why standard lichen identification protocols emphasize testing the appropriate thallus layer, particularly when distinguishing cortex and medulla chemistry [87].

Environmental and physiological conditions may also contribute to variation in the intensity of chemical reactions. The quantity of secondary metabolites can vary with thallus age, environmental conditions, substrate and physiological state. Consequently, two specimens belonging to the same species may occasionally display reactions of different intensity, particularly where the reaction is inherently weak.

There are also methodological reasons for an apparent negative result. The age and condition of reagents are important, particularly for the C test. Hypochlorite solutions lose activity over time, and weak or absent reactions can consequently result when an old reagent is used. The British Lichen Society specifically notes that C must be fresh because deterioration can produce false-negative results [22]. Similarly, some reactions are extremely rapid and may disappear within seconds, requiring careful observation. The KC test must also be performed sequentially and promptly because its diagnostic reaction depends on the interaction between the two reagents [22].

Therefore, the negative reactions documented in Table 2 should be understood as chemically informative observations rather than as an absence of chemistry. For taxa such as *Melanohalea exasperatula*, *Hypotrachyna laevigata*, *Candelariella reflexa*, *Anisomeridium biforme* and *Collema furfuraceum*, the predominantly negative reactions become useful when combined with morphology. In contrast, species such as *Flavoparmelia soredians*, *Xanthoria parietina*, *Dirinaria* spp. and *Lepraria lobificans* exhibit more conspicuous reactions that provide stronger chemical differentiation.

Overall chemical pattern of the lichen community

The results presented in Table 2 demonstrate substantial chemical heterogeneity among the 16 lichen taxa. The most pronounced reactions were observed in *Flavoparmelia soredians*, *Xanthoria parietina*, *Dirinaria applanata*, *Dirinaria picta*, *Chrysothrix candelaris* and *Lepraria lobificans*. In contrast, *Melanohalea exasperatula*, *Hypotrachyna laevigata*, *Candelariella reflexa*, *Anisomeridium biforme* and *Collema furfuraceum* exhibited predominantly negative reactions.

The results also demonstrate that no single reagent was sufficient to characterize the entire lichen assemblage. KOH produced particularly informative reactions in *F. soredians*, *D. applanata*, *D. picta* and *X. parietina*. The P test was particularly useful for *F. caperata*, *F. soredians*, *Chrysothrix candelaris*, *L. conizaeoides* and *L. lobificans*. KC provided additional information in taxa such as *F. caperata*, *F. soredians* and *L. muralis*. C, in contrast, produced few prominent reactions in the taxa examined.

The strong K+ red-purple reaction of *X. parietina* is especially important because it corresponds to the anthraquinone-rich chemistry characteristic of many Teloschistaceae and provides a readily recognizable chemical character (Orange *et al*., 2001). Similarly, the K+ yellow → red, KC+ red and P+ orange combination of *F. soredians* corresponds closely with its documented salazinic-acid chemistry [22].

The chemical profiles also demonstrate the value of integrating chemistry with morphology. For example, *D.*

applanata and *D. picta* both exhibit K+ yellow and P+ yellow reactions, so chemistry alone does not necessarily separate them; their respective thallus structures and reproductive characteristics remain important. Conversely, the K- profile of *Candelaria concolor* combined with its yellow foliose morphology provides a useful diagnostic combination, while the strong K+ red-purple response of *X. parietina* provides a highly distinctive chemical character.

Overall, the findings support the established view that lichen secondary chemistry provides important complementary characters useful for taxonomic identification and species discrimination [81, 101].

Earlier studies on lichens established that chemical characters, when combined with morphology and anatomy characteristics can, be sufficiently consistent within species to provide valuable diagnostic information [37, 87]. The present results similarly demonstrate that chemical spot testing added an additional layer of evidence for identifying the lichen taxa recorded during the survey. The combination of physical thallus characteristics, reproductive structures and chemical reactions therefore provides a more comprehensive characterization of the lichen community than morphological observation alone.

4. Conclusion

The present study provides baseline information on the diversity and characteristics of lichens occurring at the Sophia Point Rainforest Research Centre, Upper Demerara-Berbice, Guyana. A total of 16 lichen taxa were recorded, demonstrating considerable diversity in thallus architecture, colour, attachment, surface characteristics and reproductive structures. The assemblage comprised foliose, crustose, fruticose and crustose-leprose growth forms, with foliose lichens representing the most conspicuous component of the community.

The reproductive characteristics further demonstrated considerable biological diversity within the assemblage. Soredia and isidia were prominent among several taxa, while apothecia and pycnidia were also represented. The predominance of vegetative reproductive structures suggests that vegetative propagation may contribute substantially to establishment, persistence and local dispersal on tree bark, while the presence of sexually reproducing taxa demonstrates that multiple reproductive strategies occur within the community.

The study also demonstrates the usefulness of integrating morphological observations with chemical spot testing for lichen identification. The K, C, KC and P reactions provided additional diagnostic characteristics for several taxa, while predominantly negative chemical profiles were also useful when considered together with morphological features. The combination of thallus morphology, reproductive structures and chemical characteristics therefore provided a more comprehensive characterization of the recorded assemblage.

The findings further indicate that tree bark represents a heterogeneous habitat capable of supporting lichens with different ecological and structural characteristics. The occurrence of contrasting foliose, crustose and leprose forms suggests that different microsites on the bark can accommodate species with varying requirements for attachment, moisture, light and other environmental conditions. This is consistent with previous observations that bark characteristics, microclimate and host-tree properties influence lichen communities.

Lichens respond when environmental factors, substrate characteristics and atmospheric pollutants change and is often reflected in modifications in composition, abundance and distribution. These changes demonstrate the ecological significance of lichens as indicators of environmental conditions and can provide useful evidence of changes in the environmental quality of forest ecosystems. Consequently, continuous monitoring of corticolous lichen communities at Sophia Point could significantly improve the assessment of the health of the ecosystem over time.

This study therefore not only adds to the baseline knowledge of Guyana's lichen biodiversity, but also further highlights the value of lichens as useful bioindicators for monitoring the ecological condition and environmental quality of forest ecosystems.

5. Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Expand lichen inventories across inland Guyana:** Further surveys should be undertaken in Upper Demerara-Berbice and other relatively unexplored inland regions to establish a more comprehensive understanding of Guyana's lichen diversity.
2. **Increase the diversity of host trees examined:** Future investigations should include multiple native, ornamental, agroforestry and naturally occurring tree species. This would allow researchers to better assess the influence of host-tree characteristics on lichen occurrence and community composition, particularly because previous Guyanese studies have demonstrated variation among host plants.
3. **Conduct seasonal and long-term monitoring:** Repeated sampling during wet and dry seasons and over multiple years would provide information on temporal variation in lichen occurrence, abundance, reproductive activity and community composition.
4. **Measure environmental characteristics of host trees and microsites:** Future studies should incorporate bark pH, bark texture, moisture retention, tree diameter, canopy openness, light intensity, humidity and temperature. These measurements would permit stronger evaluation of the environmental factors associated with lichen distribution. Such variables are recognized as important determinants of lichen communities.
5. **Standardize quantitative sampling:** Future studies should incorporate permanent plots, fixed sampling areas or standardized grids on host trees to facilitate comparisons among sites and over time. Quantitative measurements of percentage cover, frequency and abundance should also be consistently recorded.
6. **Strengthen taxonomic verification:** Morphological identification should continue to be supported by microscopic examination, chemical spot testing and, where appropriate, molecular techniques. The study itself recognizes that combining these approaches provides stronger taxonomic evidence, particularly for tropical lichens.
7. **Establish permanent lichen monitoring sites:** Selected trees at Sophia Point could be designated as long-term monitoring substrates to determine changes in lichen community composition and abundance over time.
8. **Assess the potential of lichens as environmental indicators:** Because lichens are sensitive to environmental conditions and have been used in biomonitoring, future research at Sophia Point could examine their potential for monitoring air quality, atmospheric deposition and environmental change.

9. **Promote conservation of lichen-bearing habitats:** The maintenance of forest vegetation and mature trees should be incorporated into biodiversity conservation initiatives because tree bark provides habitat for a structurally diverse lichen assemblage.
10. **Develop a national lichen database:** Records from Sophia Point should contribute to a centralized Guyanese database containing species identity, host tree, locality, morphology, reproductive characteristics, chemical reactions and photographic documentation. Such a database would facilitate future inventories, comparisons and conservation planning.

6. Compliance with Ethical Standards

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6.2 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6.3 Disclosure of conflict of interest

The authors certify that this submission is original work and is not under review at any other publication. The authors hereby declare that this manuscript does not have any conflict of interest.

6.4 Statement of informed consent

The authors declare that informed consent was obtained from all individual participants included in the study. All work utilized in this study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

6.5 Data Availability

Data will be made available on request.

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