الجمهورية الجزائرية الديمقراطية الشعبية

Democratic and Popular Algerian Republic

وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Sciences Research

N° Ref: ……

Mila University

faculty of Natural and Life Sciences

Departement of Ecology and Environment

Thesis submitted for partial fulfillment for

The Master2 Degree

Feild: Natural Sciences and Life

Sector: Ecology and Environment

Specialization: Biodiversity and Environment

Theme:

Study of lichen biodiversity at two sites in the Mila region

Presented by :

- Kermiche Oumnia

The : 27/06/2026

In front of the jury:

Mme Keddache Lilia	MCB	President
Mme Boudjahem Ibtissam	MCB	Examiner
Mme Tayaa Hakima	MCA	Supervisor

Academic year : 2025 / 2026


بسم الله الرحمن الرحيم
Bismillahirrahmanirrahim

Special appreciation

In the name of Allah, the Most Gracious, the Most Merciful.

First and foremost, we express our deepest gratitude to Allah for granting us the strength, patience, and determination to successfully complete this work.

We would like to extend our sincere appreciation to the members of the jury for accepting to evaluate this dissertation.

***Dr. Keddache Lilia,** for kindly accepting to preside over the jury.*

***Dr. Boudjahem Ibtissam,** for accepting to examine and evaluate this work.*

*Our heartfelt and special thanks go to **Dr. Tayaa Hakima**, our supervisor, whose invaluable guidance, expertise, encouragement, and continuous support were essential throughout the realization of this research. Her insightful advice, patience, and dedication greatly contributed to the success of this study. We are deeply grateful for her trust and constant availability.*

We also wish to thank all our teachers and the staff of the Department of Biology for the knowledge and assistance they provided during our academic journey.

I would also like to express my sincere gratitude to the Forest Conservation of Mila for its valuable support and cooperation throughout this study.

*My special thanks go to **Mr. Walid, Ms. Rehane, Mrs. Katia, Mr. Boulaaras, Mr. Wahab**, and **Mrs. Amina** for their kindness, availability, assistance, and valuable guidance during the fieldwork. Their support and cooperation greatly contributed to the successful completion of this research.*

Finally, I would like to thank everyone who contributed, directly or indirectly, to the accomplishment of this work.

Thank You All.

Dedication

To my beloved mother, Asia…

To the heart that loved me before I even came into this world,

to the prayers that always walked ahead of me on every road,

you are the light that never fades, no matter how dark the days become.

To my dear father, Mohamed…

To the man who taught me that every dream is worth the struggle,

and who remained my strongest support through every challenge,

words will never be enough to express my gratitude to you.

*To my brothers**, Mahmoud, Abderrahmane, Alaa, Souhaib, and Rdjem…***

You are my strength in moments of weakness,

my comfort in difficult times,

and the reason this journey felt lighter and more meaningful.

*And to my dear friends**, Kenzoz, Lina Maali, Chahinaz, Chaima, and Kholoud …***

Thank you for being the beautiful company during my hardest days,

for every moment of support, laughter, and sincere friendship that made this journey brighter.

I dedicate this work to all of you…

For you are the most beautiful part of every success I achieve,

and the sincere souls who stood beside me until the very end.

Omnia Kermiche

ABSTRACT

The present study aims to assess the diversity and distribution of corticolous lichens in the forests of Baïnan and Tamentout, located in the Mila region (Northeastern Algeria). Field surveys were carried out on different host-tree species in order to establish a lichen inventory and evaluate the influence of ecological factors on lichen communities. The inventory revealed the presence of 17 corticolous lichen species belonging to 14 genera, 8 families, 7 orders and one class *(Lecanoromycetes*). The results showed a higher species richness in Tamentout forest (15 species) compared to Baïnan forest (11 species), associated with a greater lichen coverage and a more diversified lichen community. The analysis of host trees indicated that *Quercus afares* supported the highest lichen diversity, whereas *Quercus zeen* showed lower values. Ecological indices revealed a more balanced and stable community structure in Tamentout forest. The Jaccard similarity index indicated a moderate similarity between the two forests, reflecting the influence of both common regional conditions and local ecological factors. The occurrence of sensitive species such as *Lobaria pulmonaria, Evernia prunastri* and *Hypogymnia physodes* suggests relatively favorable environmental conditions and satisfactory ecological quality, particularly in Tamentout forest. The observed differences in lichen diversity appear to be mainly related to altitude, humidity, microclimatic conditions and host-tree characteristics. These results highlight the ecological importance of Mediterranean ***oak*** forests as reservoirs of lichen biodiversity and confirm the value of lichens as bioindicators of environmental quality.

Keywords: Corticolous lichens, biodiversity, species richness, ecological indices, bioindicators, host trees, Mediterranean forests, Baïnan, Tamentout, Mila.



RESUME

La présente étude vise à évaluer la diversité et la distribution des lichens corticoles dans les forêts de Baïnan et de Tamentout, situées dans la région de Mila (Nord-Est de l'Algérie). Des prospections de terrain ont été réalisées sur différentes espèces d'arbres hôtes afin d'établir un inventaire des lichens et d'évaluer l'influence des facteurs écologiques sur leurs communautés. L'inventaire a révélé la présence de 17 espèces de lichens corticoles appartenant à 14 genres, 8 familles, 7 ordres et une classe (*Lecanoromycetes*). Les résultats ont montré une richesse spécifique plus élevée dans la forêt de Tamentout (15 espèces) par rapport à celle de Baïnan (11 espèces), associée à un taux de recouvrement plus important et une communauté lichénique plus diversifiée. L'analyse des arbres hôtes a indiqué que *Quercus afares* abritait la plus grande diversité de lichens, tandis que *Quercus zeen* présentait les valeurs les plus faibles. Les indices écologiques ont révélé une structure de communauté plus équilibrée et stable dans la forêt de Tamentout. L'indice de similarité de Jaccard a indiqué une similitude modérée entre les deux forêts, reflétant l'influence à la fois des conditions régionales communes et des facteurs écologiques locaux. La présence d'espèces sensibles telles que *Lobaria pulmonaria*, *Evernia prunastri* et *Hypogymnia physodes* suggère des conditions environnementales relativement favorables et une qualité écologique satisfaisante, particulièrement dans la forêt de Tamentout. Les différences de diversité lichénique observées semblent être principalement liées à l'altitude, l'humidité, les conditions microclimatiques et les caractéristiques des arbres hôtes. Ces résultats mettent en évidence l'importance écologique des forêts de chênes méditerranéennes en tant que réservoirs de biodiversité lichénique et confirment la valeur des lichens comme bioindicateurs de la qualité de l'environnement.

Mots-clés : Lichens corticoles, biodiversité, richesse spécifique, indices écologiques, bioindicateurs, arbres hôtes, forêts méditerranéennes, Baïnan, Tamentout, Mila.



الملخص

هدف الدراسة الحالية إلى تقييم تنوع وتوزيع الأشنات القشرية في غابتي باينان وتامنتوت، الواقعتين في منطقة ميلة (شمال شرق الجزائر). وقد أجريت مسوح ميدانية على أنواع مختلفة من الأشجار المضيفة بهدف إعداد جرد للأشنات وتقييم تأثير العوامل البيئية على مجتمعاتها. وكشف هذا الجرد عن وجود 17 نوعا من الأشنات القشرية تنتمي إلى 14 جنسا، و8 عائلات، و7 رتب، وفئة واحدة .(Lecanoromycetes) وأظهرت النتائج ثراء نوعيا أعلى في غابة تامنتوت (15 نوعا) مقارنة بغابة باينان (11 نوعا)، مصحوبا بنسبة غطاء أشناتي أكبر ومجتمع أشنات أكثر تنوعا. كما أشار تحليل الأشجار المضيفة إلى أن بلوط العفص (Quercus afares) يدعم أعلى تنوع للأشنات، في حين سجل بلوط الزان (Quercus zeen) قيما أقل. وكشفت المؤشرات البيئية عن بنية مجتمعية أكثر توازنا واستقرارا في غابة تامنتوت. من جهة أخرى، أشار مؤشر جاكارد للتشابه إلى وجود تشابه معتدل بين الغابتين، مما يعكس تأثير كل من الظروف الإقليمية المشتركة والعوامل البيئية المحلية. ويوحي وجود أنواع حساسة مثل Lobaria pulmonaria و Evernia prunastriو Hypogymnia physodesبظروف بيئية مواتية نسبيا وجودة بيئية مرضية، لا سيما في غابة تامنتوت. ويبدو أن الاختلافات الملاحظة في تنوع الأشنات ترتبط أساسا بالارتفاع، والرطوبة، والظروف المناخية الدقيقة(microclimatic) ، وخصائص الأشجار المضيفة. وتبرز هذه النتائج الأهمية البيئية لغابات البلوط المتوسطية كخزانات للتنوع البيولوجي للأشنات، وتؤكد قيمة الأشنات كمؤشرات حيوية لجودة البيئة.

الكلمات المفتاحية :الأشنات القشرية، التنوع البيولوجي، الثراء النوعي، المؤشرات البيئية، المؤشرات الحيوية، الأشجار المضيفة، الغابات المتوسطية، باينان، تامنتوت، ميلة.

TABLES LIST

N°	Titel	page
01	Legal and administrative status of the zwagha forest	27
02	Legal and administrative status of the tamentout forest	30
03	General characteristics of the studied forests (bainan/tamentout	40
04	average altitude according to tree species in bainan forest	41
05	average lichen coverage according to tree species in bainan forest	42
06	average altitude according to tree species in tamentout forest	43
07	average lichen coverage according to tree species in bainan forest	43
08	Characteristics of the lichen species identified in the two forests(bainan-tamentout)	44
09	Taxonomic classification of the lichen species recorded in bainan and tamentout forests	50
10	species richness in the two study sites	51
11	species richness in the bainan forest	51
12	species richness in the Tamentout forest	52
13	frequency of occurrence in the two forests	52
14	shannon-wiever diversity index and equitqbility in the two study sites	53
15	shannon-wiever diversity index and equitqbility according to host tree species in the two sites	55
16	Simpson diversity index in the two study sites	56
17	simpson index according to host tree species in the two sites	56

LIST OF FIGURES

N°	Titel	page
01	Lichens, bioindicators of air quality	**04**
02	Schematic representation of lichen symbiosis	**05**
03	Lichen is made up of two types of fungus and an alga	**05**
04	Illustration of an ascolichen, a lichen whose fungal partner belongs to the *phylum Ascomycota*	**06**
05	Photobionts isolated from Dermatocarpon luridum var. *Luridum and D. Luridum var*. Decipiens grown in liquid medium	**07**
06	Nutritional exchanges between lichen partners (mycobiont, photobiont, etc.).	**08**
07	Electron microscopy images of a homomeric structure (left) and a heteromeric structure (right	**09**
08	Main types of lichen thalli	**11**
09	Reproductive organs of lichens: (a) *apothecia*, (b) *lirelles*, (c) *perithecia*, (d) *soralia*, (e*) isidia*	**13**
10	crustacean thallus	**15**
11	Squamulose thallus	**15**
12	Gelatinous thallus (*Lathagrium auriforme)*	**16**
13	Foliose thallus (*Lobaria pulmonaria*, on an alder trunk, a few minutes after a spritzing of water	**17**
14	Fruticose thallus *(Usnea filipendula)*	**17**
15	Leprose thallus	**18**
16	map of the situation in the wilaya of Mila	**21**
17	climate map of the wilaya of mila	**22**
18	The monthly average temperature in Mila between (2015-2025)	**22**
19	The monthly average humidity in Mila between (2015-2025)	**23**
20	The monthly average of precipitation in Mila between (2015-2025)	**24**
21	The monthly average sunshine duration in Mila between (2015-2025)	**24**
22	The monthly average of wind speed in Mila between (2015-2025)	**25**
23	Altimeter map of the wilaya of Mila	**26**
24	Geographical location map of the zwagha forest	**27**
25	Geographical location map of the tamentout forest	**29**
26	the average altitude between the two forests(bainan-tamentout)	**41**

27	the average lichen coverage between the two forests(bainan-tamentout)	**41**
28	the average altitude of tree species in bainan forest	**42**
29	the average lichen coverage according to tree species in bainan forest	**42**
30	the average altitude of tree species in tamentout forest	**43**
31	the average lichen coverage according to tree species in tamentout forest	**43**
32	comparison of species richness between bainan and tamentout forests	**51**
33	species richness according to host tree species in bainan forests	**51**
34	species richness according to host tree species in tamentout forests	**52**
35	frequency of occurrence, comparison between the two forests	**53**
36	comparison of shannon-weaver diversity index between bainan and tamentout	**54**
37	comparison of Equitqbility between bainan and tamentout forests	**54**
38	shannon-wiever diversity index of site 01 et 02, B: Equitqbility index of site 01 et 02 all according to host tree species	**55**
39	comparison of simpson index between bainan and tamentout forests	**56**
40	simpson index according to trees species in bainan and tamentout forests	**57**
41	Distribution of common and non-common species between the two sites	**57**

LIST OF PHOTOS

N°	Titel	page
01	Predominant forest species of the zwagha forest	**28**
02	Predominant forest species of the tamentout forest	**30**
03	grid divided into five squares measuring 15 × 15 cm	**31**
04	A knife	**32**
05	A GPS application installed on a smartphone	**32**
06	Plastic bags	**33**
07	Guide of lichens	**33**
08	An iPhone 13 smartphone	**34**
09	Ruban metrique	**34**
10	lichen sampling data sheet	**34**
11	Sampling Design for trees	**35**
12	Sampling Design for lichen	**36**
13	Data Collection of lichen	**36**

ABRIVIATION TABLE

%	Percentage
GPS	Global positioning sustem
S	Species richness
ln	Natural logarithm
J	Jaccard similarity index
m	meter
RF (%)	Relative frequency
D	Simpson diversity index
E	Equitability index
H'	Shannon-wiener diversity index
$\sum$	summation
NO2	Nitrogen dioxide
GDF	General directorate of forests mila

TABLE OF CONTENTS

INTRODUCTION 1

1. LITERATURE REVIEW 4

1.1 General overview of lichens 4

1.1.1 Definition and Symbiotic Nature 4

1.1.2 Symbiotic Organization and Physiological Integration 5

1.1.2.1 Fungal Partner (Mycobiont) 5

1.1.2.2 Photosynthetic Partner (Photobiont) 7

1.1.2.3 Bactériobiantes 8

1.1.3 Anatomical structure of Lichens 8

1.1.3.1 Homeomeric structure 8

1.1.3.2 Heteromeric structure 9

1.1.4 Morphology of the Lichen Thallus 9

1.1.5 Major Ecological Groups of Lichens 11

1.1.5.1 Terricolous and Humicolous Lichens 11

1.1.5.2 Corticolous Lichens 11

1.1.5.3 Saxicolous Lichens 12

1.1.6 Reproduction of Lichens 12

1.1.6.1 Asexual Reproduction 12

1.1.6.2 Sexual Reproduction 13

1.1.7 Growth and Longevity 13

1.1.8 Lichen Systematics and Classification 14

1.1.8.1 Classification According to Thallus Morphology 14

a. Crustose 14

b. Squamulose 15

c. Gelatinous 15

d. Foliose 16



e. Fruticose 16
f. Leprose 17
1.1.8.1 Classification Based on the Fungal Component 18
1.1.9 Lichen Ecology 18
1.1.10 Lichens as Environmental Proxies 19
1.1.11 Economic and Applied Uses of Lichens 19
1.1.11.1 Food Applications 19
1.1.11.2 Medicinal and Pharmaceutical Uses 20
1.1.11.3 Industrial Applications 20
1.2 The study area 21
1.2.1 Geographical location of Mila region 21
1.2.2 Climate Characteristics 21
1.2.2.1 Temperature 22
1.2.2.2 Humidity 23
1.2.2.3 Precipitation 23
1.2.2.4 Sunshine Duration 24
1.2.2.5 wind speed 24
1.2.3 Topographical Framework 25
2. MATERIAL AND METHODS 27
2.1 Description of the selected sites 27
2.1.1 Site of Zwagha Bainan (Amira aras/tassala matai) 27
2.1.1.2 Selection of Sampling Points and Number of Samples 29
2.1.2. Site of Tamentout (Tessadane Haddada) 29
2.1.1.2 Selection of Sampling Points and Number of Samples 31
2.2 materials and equipment 31
2.2.1 sampling tools 31
2.3 Field Data Collection 35

2.4 Sampling Design and Data Collection 35
2.5 Identification of Lichen Species 37
2.6 Biodiversity Assessment 37
2.6.1 Species Richness 37
2.6.2 Frequency of occurrence 38
2.6.3 Shannon–Wiever Index 38
2.6.4 Equitability 39
2.6.5 Simpson Index 39
2.6.6 Jaccard Similarity Index 39
2.7 Statistical Analysis 40
3. RESULTS 40
3.1 General characteristics of the study sites 40
3.1.1 site 01 41
3.1.2 site 02 42
3.2 Characteristics of the lichen species identified in the two sites 44
3.3 taxonomic classification of the recorded lichen species 50
3.4 Ecological indices 50
3.4.1 Species Richness 50
3.4.1.1 site 01 51
3.4.1.2 site 02 52
3.4.2 Frequency of occurrence 52
3.4.3 shannon-wiever and Equitability 54
3.4.4 simpson index 55
3.4.5 Jaccard Similarity Index 57
4. DISCUSSION 58
CONCLUSION 66
REFERENCES 68

Introduction



INTRODUCTION

Lichens are complex and fascinating organisms resulting from a stable symbiotic association between a fungus (the mycobiont) and a photosynthetic partner, which can be either a green alga or a cyanobacterium. This biological cooperation allows lichens to survive in a wide range of environmental conditions, including habitats where other plant organisms may struggle to grow. Because they lack roots and absorb water and nutrients directly from the atmosphere, lichens are highly influenced by surrounding environmental factors **(Nash, 2008).**

Beyond their biological particularity, lichens play an essential ecological role in forest ecosystems. They contribute to nutrient cycling, participate in the slow weathering of rocks, and provide microhabitats for various invertebrates and microorganisms. In Mediterranean regions, where climatic conditions can vary significantly between seasons, lichens are considered an important component of forest biodiversity **(Purvis, 2000).**

The biodiversity of lichens varies considerably from one environment to another due to the influence of several ecological and climatic factors. Parameters such as air quality, humidity, temperature, altitude, light exposure, and the nature of the substrate (tree bark, rocks, or soil) strongly affect the distribution and abundance of lichen species. In forest ecosystems, the diversity of tree species and the structure of vegetation also play an important role in shaping lichen communities. Furthermore, anthropogenic disturbances such as urbanization, industrial pollution, and deforestation may reduce lichen diversity, since many species are highly sensitive to environmental changes. Consequently, lichens are widely recognized as valuable bioindicators for evaluating ecosystem quality and environmental stability (**Hawksworth & Hill, 1984; Nash, 2008; Giordani, 2007).**

One of the most studied characteristics of lichens is their sensitivity to atmospheric pollution. Due to their direct exposure to air and absence of protective tissues, they accumulate pollutants such as heavy metals and other airborne contaminants. For this reason, lichens have been widely used as bioindicators of air quality and environmental disturbance in both urban and forested ecosystems. Several studies have confirmed this ecological role, notably the review conducted by **Maria** and **Giorgio (2001)**, which demonstrated the effectiveness of lichens in monitoring atmospheric pollution through the analysis of species diversity and pollutant accumulation. Likewise, **Paolo (2007)** showed that areas exposed to higher levels of pollution generally present lower lichen diversity and abundance. Variations in species richness,

abundance, and cover therefore often reflect differences in ecological conditions and environmental quality.

In Algeria, lichenological studies remain relatively limited compared to other botanical groups. Although several researchers have contributed to the documentation of lichen flora at the national level, many regions still lack detailed and updated inventories. This gap is particularly noticeable in certain forest ecosystems of northeastern Algeria, where local biodiversity assessments are still insufficient **(Rebbas, 2011).** Nevertheless, some important studies have provided valuable information on Algerian lichen diversity. For instance, **Khellaf** and his collaborators **(2011)** conducted an inventory of lichens in the Gouraya National Park (Bejaia), where they identified several species and emphasized the ecological significance of lichens in biodiversity conservation. In addition, **Mohamed and colleagues (2014)** updated the checklist of Algerian lichens and reported more than one thousand taxa distributed across the country. Furthermore, studies carried out in El Kala National Park by **Fadel Djamel (2018)** demonstrated that lichen distribution varies according to climatic conditions and forest composition. More recently, **Amina *et al.* (2022)** investigated epiphytic lichens growing on oak trees in the Tamentout forest and highlighted the influence of host tree species and environmental factors on lichen diversity.

The Mila region possesses important forest and ecological resources that may support a significant lichen diversity. However, studies concerning lichens in this area remain relatively limited and fragmented. Among the few available investigations, the work carried out by **Amina** focused on lichen communities associated with a forest ecosystem and provided preliminary information about the composition of epiphytic lichens in this environment. Another study conducted by **Menar and Fayrouz (2022)** examined lichens in urban areas of Mila, particularly their relationship with environmental conditions and air quality. Nevertheless, despite these contributions, several forest ecosystems of Mila have not yet been explored from a lichenological perspective. In addition, no comparative research has been undertaken to evaluate the variation of lichen biodiversity between different forests of the region according to ecological and climatic factors. Consequently, further investigations are necessary to enrich the existing data and improve the understanding of lichen distribution in the forests of Mila.

The forests of Zawaga Baïnan (Amira aras /tassala lamtai) and Tamentout (tassaddane Hadada), located in the Mila region, represent two Mediterranean forest ecosystems characterized by distinct ecological and environmental conditions. Variations in vegetation

structure, substrate composition, and microclimatic parameters between these two sites are likely to influence the distribution, abundance, and diversity of lichen communities. However, no comprehensive comparative study has yet been conducted specifically to evaluate lichen biodiversity between these two forest ecosystems.

Therefore, the present study aims to assess and compare lichen biodiversity in the forests of Zawaga Baïnan (Amira aras /tassala lamtai) and Tamentout (Tessadane Haddada) by establishing a detailed species inventory, analyzing their abundance and cover, and examining the relationship between environmental factors and species distribution patterns. This research is structured into four main chapters in order to address the different components of the study in a coherent manner.

The first chapter provides a comprehensive literature review on lichens, including their definition, symbiotic organization, morphology, reproduction, classification, ecology, and their importance as bioindicators of environmental quality, as well as their various ecological applications.

The second chapter is dedicated to the materials and methods used in this study. It describes the study sites, sampling design, field data collection procedures, species identification techniques, biodiversity indices applied, and the statistical methods used for data analysis.

The third chapter presents the results obtained from the study. It includes an analysis of species richness, community composition, distribution of lichen growth forms, and a comparative evaluation of biodiversity between the two study sites, supported by tables and graphical representations.

The fourth chapter discusses the results in relation to environmental conditions, explores the influence of ecological and anthropogenic factors on lichen distribution, compares the findings with previous studies conducted in similar Mediterranean forest ecosystems, and highlights their ecological significance.

Finally, the study concludes with a general synthesis of the main findings and proposes perspectives for future research aimed at improving knowledge of lichen diversity in forest ecosystems of northern Algeria.

Literature Review



1. LITERATURE REVIEW

1.1 General overview of lichens

1.1.1 Definition and Symbiotic Nature

The term "lichen" comes from the Greek word "*leikhēn*", meaning "to lick" or "licker", which was used historically to describe the crusty, spreading appearance of some lichen species on rocks and trees **(Ahmadjian, 1993).** Lichens are composite organisms formed by a stable symbiotic association between a fungal partner (mycobiont) and a photosynthetic partner (photobiont), which can be either a green alga or a cyanobacterium **(Nash, 2008).**



Figure 01. Lichens, bioindicators of air quality **(Laetitia,2023)**

In this partnership, the fungus provides structure, protection, and water retention, while the photobiont performs photosynthesis and produces organic nutrients that sustain both partners. This mutualistic relationship allows lichens to survive in environments where neither organism could survive alone, from bare rocks in deserts to tree bark in humid forests **(Ahmadjian, 1993; Honegger, 1991).**

The lichen body, called the thallus, comes in different forms depending on the species: crustose (crust-like, tightly attached to the substrate), foliose (leaf-like, loosely attached), or fruticose (shrub-like, branched). The fungal hyphae envelop the photobiont cells, creating a highly organized structure that maximizes light capture, water retention, and gas exchange **(Honegger, 1991; Brodo *et al.*, 2001).**

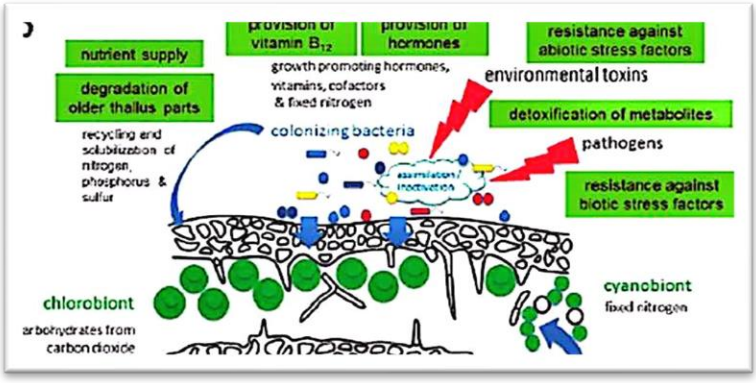


Figure 02. Schematic representation of lichen symbiosis **(figure adapted from Grube *et al*., 2015)**

1.1.2 Symbiotic Organization and Physiological Integration

1.1.2.1 Fungal Partner (Mycobiont)

The fungal component involved in the formation of lichens is referred to as the lichen mycobiont. Within the lichen symbiosis, the fungus represents the structural framework of the association and plays a central role in maintaining the stability of the symbiotic system. The mycobiont forms an extensive network of fungal filaments known as hyphae, which surround and support the photosynthetic partner. Through this structural organization, the fungus contributes to the formation of the lichen thallus and ensures the cohesion of the symbiotic organism. Moreover, the fungal partner plays a protective role for the photosynthetic cells, particularly by reducing the effects of environmental stresses such as dehydration. This protective function is essential because the algal cells are sensitive to desiccation and require a stable microenvironment to maintain their metabolic activity **(Van Haluwyn *et al*., 2009).**



Figure 03. Lichen is made up of two types of fungus and an alga **(Spribille *et al*.,2016)**

In addition to providing structural support and protection, the fungal partner is alsoresponsible for the absorption of water and mineral nutrients from the surrounding environment. The fungal hyphae are directly connected with both the atmosphere and the substrate on which the lichen grows. This position allows the fungus to capture moisture as well as dissolved mineral salts from rainwater, atmospheric deposits, or the substrate surface. Once absorbed, these resources are transferred to the photosynthetic symbiont, often referred to as the photosymbiont or photobiont. In return, the photosynthetic partner produces organic compounds through the process of photosynthesis, which contribute to the nutrition of the entire symbiotic association. This exchange of resources between the two partners illustrates the complementary roles that characterize lichen symbiosis **(Van Haluwyn *et al*., 2009).**

From a taxonomic perspective, most lichen-forming fungi belong to the ***phylum Ascomycota***. According to current knowledge, nearly 99% of known lichens are associated with ascomycete fungi, and these lichens are therefore commonly referred to as ***ascolichens***. This predominance of ascomycetes demonstrates their major role in the evolution and diversification of lichen symbiosis **(Feuerer & Hawksworth, 2007)**. In contrast, only a small proportion of lichens involve fungal partners belonging to the Basidiomycota. When the fungal symbiont belongs to this group, the resulting lichen is known as a basidiolichen. However, the phenomenon of lichenization within basidiomycetes is relatively rare compared with that observed in ascomycetes. Indeed, only about 1 to 2% of all lichens are formed by basidiomycete fungi, which highlights the exceptional nature of these associations **(Honegger, 2008).**

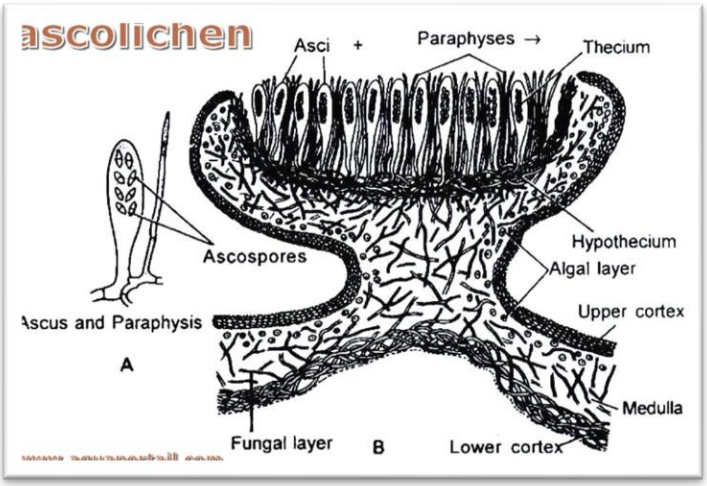


Figure 04. Illustration of an ascolichen, a lichen whose fungal partner belongs to the *phylum Ascomycota.* **(Aquaportail.2011).**

1.1.2.2 Photosynthetic Partner (Photobiont)

Photobionts, also called photosymbionts, are the algal partners within lichens that carry out photosynthesis, producing the organic carbon necessary to sustain the fungal partner. These symbiotic algae are crucial for the lichen's survival, especially in nutrient-poor or extreme habitats. According to **Van Haluwyn *et al.* (2009),** around 90% of photobionts belong to the class Chlorophyceae, commonly known as green algae, which are well adapted to withstand desiccation and fluctuating environmental conditions.

Lichens exhibit a remarkable diversity of photobionts, with nearly 40 genera of algae and cyanobacteria reported as partners. Among them, the genera Trebouxia, Trentepohlia, and Nostoc are the most frequently observed across different lichen species **(Friedl & Büdel, 2008).** While Trebouxia and Trentepohlia contribute primarily through photosynthesis, Nostoc additionally provides an important ecological function by performing nitrogen fixation, enriching the substrate and supporting lichen growth in nutrient-limited environments.

Overall, the type, abundance, and diversity of photobionts significantly affect lichen morphology, reproductive success, growth rate, and ecological adaptability. Studying these associations provides essential insights into the symbiotic mechanisms of lichens and their resilience in diverse ecosystems **(Van Haluwyn *et al.*, 2009; Friedl & Büdel, 2008).**

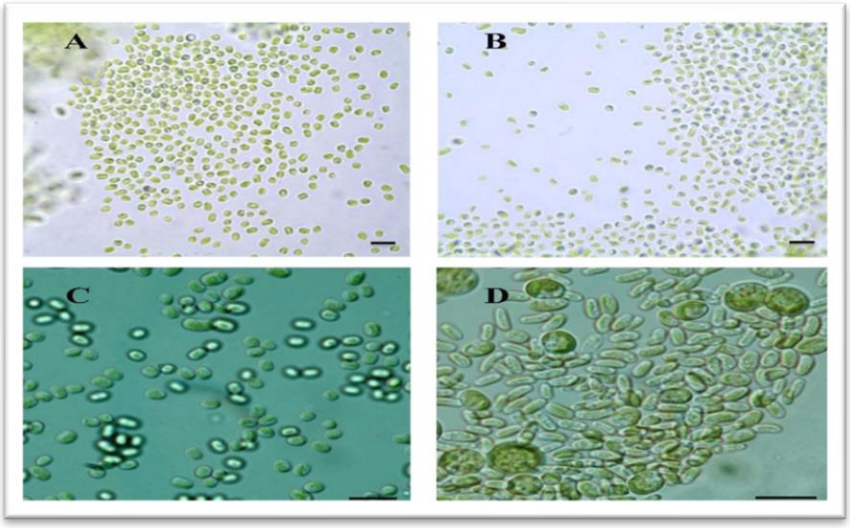


Figure 05. Photobionts isolated from Dermatocarpon luridum var. *Luridum and D. Luridum var*. Decipiens grown in liquid medium **(Fontaine *et al.*,2012)**

1.1.2.3 Bactériobiantes

In addition to the fungal partner (mycobiont) and the photosynthetic partner (photobiont), lichens can also harbor bacterial partners, commonly referred to as bacteriobionts **(Nash, 2008)**. These bacteria coexist within the lichen thallus and form part of the extended symbiotic community, contributing to the overall functioning of the lichen symbiosis **(Honegger, 2008)**. Bacteriobionts are believed to play roles in nutrient cycling, including the transformation and mobilization of minerals, as well as in the production of biologically active compounds that may enhance the lichen's tolerance to environmental stress **(Nash, 2008).** Although bacterial associations in lichens have received less attention in classical mycological texts compared to the fungal and algal components, comprehensive works on lichen biology acknowledge the presence and potential ecological significance of these microbial partners as part of a more complex symbiotic network **(Honegger, 2008)**. Their presence supports the concept that lichens are not merely dual partnerships but can involve additional microbial contributors that influence lichen ecology and function **(Nash, 2008).**

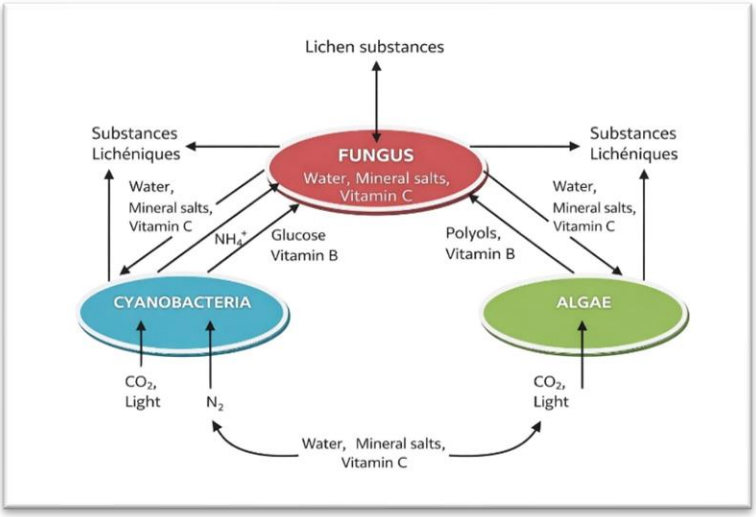


Figure 06. Nutritional exchanges between lichen partners (mycobiont, photobiont, etc.). **(Van Haluwyn *et al.* (2009)**

1.1.3 Anatomical structure of Lichens

1.1.3.1 Homeomeric structure

In lichen thalli, a homomeric structure refers to a simple internal organization in which the fungal hyphae and the photosynthetic algal cells are distributed uniformly throughout the thallus without forming distinct stratified layers **(Jahns & Henssen, 1973)**. In this configuration, the algal and fungal components are intermixed, resulting in a thallus that lacks

a clearly defined cortex or algal zone, and the partners are in close physical contact across the body of the lichen **(Witts, 2023)**. This type of structure is typically found in gelatinous and crustose lichens, where the symbiotic partners are evenly dispersed within the lichen body and do not form separate tissue layers **(Jahns & Henssen, 1973)**. The term homomeric highlights the absence of internal differentiation in contrast to the more complex heteromeric (stratified) thalli found in many foliose and fruticose lichens. **(Witts, 2023).**

1.1.3.2 Heteromeric structure

This type of structure is characterized by the dominance of the fungal partner (mycobiont) within the lichen symbiosis, where the arrangement of tissues reflects an organized stratification under the influence of the fungus. In a heteromeric thallus, the mycobiont and the photosynthetic partner (photobiont) form distinct, individualized layers, with the fungal hyphae typically comprising the outer cortex and lower medulla, while the photobiont cells are concentrated in a separate algal layer beneath the cortex. Such stratification allows the partners to occupy specialized zones that optimize light capture, gas exchange, and nutrient distribution across the thallus. An example of this structural organization can be observed in species such as Lecidella elaeochroma, where the differentiation of layers is clear and reflects the functional roles of each symbiotic component **(Douibi ,2020).**

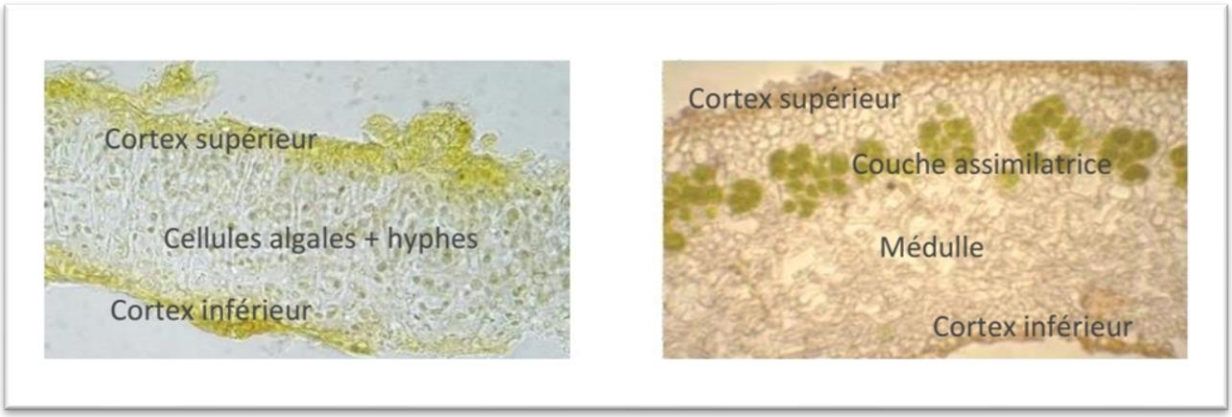


Figure 07. Electron microscopy images of a homomeric structure (left) and a heteromeric structure (right) **(after Aprile *et al*., 2011).**

1.1.4 Morphology of the Lichen Thallus

The morphology of lichens is mainly determined by the fungal partner (mycobiont), which plays a major role in organizing the thallus and shaping its external appearance. The thallus represents the vegetative body of the lichen and supports the reproductive structures. Lichens display a remarkable diversity of shapes, sizes, and colors, which allows them to be

classified into several morphological types) "figure 08" **(Van Haluwyn *et al*., 2009; Purvis *et al.*, 1992).**

Crustose lichens are the most common morphological form and represent nearly 90 % of known species. They develop as thin crust-like layers that adhere strongly to the substrate and may penetrate it to different depths, making them difficult to remove without damaging the surface **(Van Haluwyn *et al*., 2009; Purvis *et al*., 1992).**

Foliose lichens are characterized by a leaf-like thallus composed of flattened lobes that may be entire or divided. These thalli are generally loosely attached to the substrate and can be detached more easily compared with crustose forms" figure 08 b" **(Van Haluwyn *et al*., 2009).**

Fruticose lichens have a shrubby or filamentous structure composed of cylindrical or ribbon-like branches that may be erect or pendent. In most cases, they are attached to the substrate by a reduced basal area or a single point of contact" figure 08 c" **(Purvis *et al*., 1992).**

Composite or complex lichens consist of a primary thallus attached to the substrate and a secondary upright structure that may be branched or trumpet-shaped, commonly referred to as a podetium" figure08 d" **(Van Haluwyn *et al*., 2009).**

Squamulose lichens are composed of small scale-like structures called squamules that may partially overlap on the substrate surface" figure 08 e" **(Purvis *et al*., 1992).**

Gelatinous lichens are generally dark and brittle when dry but become gelatinous in humid conditions due to the presence of cyanobacterial photobionts. Their morphology may resemble foliose, crustose, squamulose, or fruticose forms "figure 08 f" **(Honegger, 1991).**

Leprose lichens are characterized by a powdery thallus composed of granules that detach easily from the substrate" figure08 g" **(Van Haluwyn *et al*., 2009)**.

In addition to the main morphological types of lichens, the surface of the thallus may present various specialized structures that play an important role in growth and vegetative reproduction. Among these structures are soredia and isidia, which are small propagules containing both fungal hyphae and algal cells. These structures allow lichens to disperse efficiently and colonize new substrates. The presence, abundance, and morphology of these vegetative propagules are often used as important diagnostic characters in the identification of lichen species. Furthermore, the external morphology of the thallus can vary depending on environmental conditions such as light intensity, humidity, and substrate composition, which

may influence the development and distribution of different lichen growth forms **(Ahmadjian, 1993; Nash, 2008).**



Figure 08. Main types of lichen thalli **(Daoudi,2016)**

1.1.5 Major Ecological Groups of Lichens

1.1.5.1 Terricolous and Humicolous Lichens

Terricolous lichens are those that develop on soil or humus, with the entire thallus located on the surface of the substrate, while still producing hyphal structures that penetrate and anchor into it **(Ozenda & Clauzade, 1970)**. These lichens are crucial for the ecological stability of soil crusts, contributing to physical integrity, water regulation, and supporting the development of soil microflora **(Singh & Sinha, 1997)**. Their presence enhances soil cohesion and influences nutrient cycling, making them important components of terrestrial ecosystems.

1.1.5.2 Corticolous Lichens

Corticolous lichens are those that grow primarily on the branches and bark of tree trunks. They represent one of the most abundant and morphologically complex groups of lichens **(Ait Hammou, 2015)**. Unlike some other lichen types, corticolous species do not derive nutrients directly from the substrate; instead, they rely entirely on their photobionts for photosynthesis and nutrition. However, their growth and distribution are strongly influenced by the physical and chemical properties of the bark, including water retention capacity, texture and sponginess, pH, and other chemical characteristics **(Sérusiaux et al., 2004)**. These factors play a crucial role in determining which lichen species can establish and thrive on a given tree, highlighting the sensitivity of corticolous lichens to their immediate microhabitat.

1.1.5.3 Saxicolous Lichens

Saxicolous lichens, also referred to as rupicolous lichens, are species that primarily grow on rocks and rocky surfaces **(Sérusiaux *et al*., 2004)**. According to **Olivier (2006),** these lichen communities are frequently found on siliceous rocks, cliffs, walls, and even rooftops. They exhibit a strong adhesion to their substrate and may become partially or entirely incorporated into it, which provides them with stability and resilience against environmental stresses. Saxicolous lichens constitute the most widely represented group, encompassing over three-quarters of all known lichen species **(Ozenda & Clauzade, 1970)**. They are distinguished by their high diversity, abundance, and global presence **(Gregory & Dimijian, 2003)**. Moreover, the type of substrate—such as limestone or siliceous rock—often allows field researchers to preliminarily identify certain species, as many saxicolous lichens show substrate-specific preferences **(Boistel, 1986)**. This combination of abundance, diversity, and ecological specificity makes saxicolous lichens a crucial subject of study for understanding lichen biodiversity and distribution patterns.

1.1.6 Reproduction of Lichens

1.1.6.1 Asexual Reproduction

Vegetative reproduction in lichens occurs through the detachment of propagules that contain both the photobiont and the mycobiont, enabling the simultaneous dispersal of the two symbiotic partners. These propagules can be classified into two main types. First, soredia (figure 09 d) are small granular structures formed by a tight aggregation of algal cells and fungal hyphae. They emerge from specialized openings on the upper surface of the lichen thallus, facilitating efficient dispersal and colonization of new substrates by both partners. Second, isidia (figure 09 e) are small outgrowths of the lichen cortex that also contain both algal and fungal components **(Rennes, 2017).** Unlike soredia, isidia remain partially attached to the thallus for some time before detaching, which can enhance the establishment of the lichen in suitable microhabitats. Both soredia and isidia play a crucial role in the survival and propagation of lichens, particularly in environments where sexual reproduction is limited or unfavorable. Their presence and abundance are often important taxonomic characters used in species identification and ecological studies.

1.1.6.2 Sexual Reproduction

Sexual reproduction in lichens involves only the fungal partner and is an essential mechanism for generating genetic diversity within lichen populations. This process occurs through specialized reproductive structures such as the apothecium, lirella, and perithecium (Figure 09 a, b, and c). Within these structures, the fungus produces sexual spores that are released into the air. Once dispersed, these spores must encounter a compatible algal partner in order to form a new lichen thallus. The success of this process depends on the environmental conditions and the presence of suitable photobionts in the surrounding habitat. Sexual reproduction is particularly important for colonizing new areas and for maintaining the evolutionary adaptability of lichen populations, complementing vegetative reproduction strategies that propagate both fungal and algal partners simultaneously (**Honegger, 2008; Sérusiaux *et al*., 2004).**

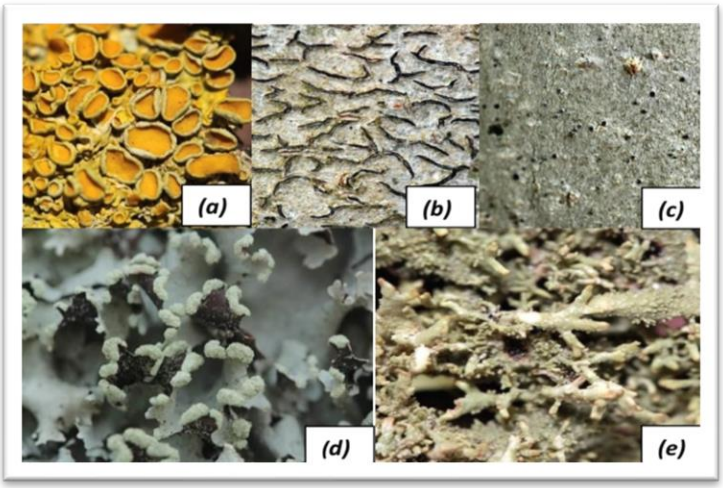


Figure 09. Reproductive organs of lichens: (a) *apothecia*, (b) *lirelles*, (c) *perithecia*, (d) *soralia*, (e*) isidia* **(Douibi. Ch,2020)**

1.1.7 Growth and Longevity

Lichens are characterized by their slow growth rates and remarkable longevity, which contribute to their ecological stability and resilience in diverse habitats. Among the different types of lichens, crustose forms exhibit the slowest growth, averaging between 2 and 3 millimeters per year, due to their tight adherence to the substrate and compact thallus structure **(Collombet, 1989)**. In contrast, foliose and fruticose lichens, which are less firmly attached, tend to grow more rapidly, with annual increases ranging from 3 to 4 centimeters. This variability in growth rate is closely related to the degree of substrate attachment and the morphology of the thallus. Regarding longevity, fruticose and composite thalli typically reach

a minimum age of around 10 years, reflecting their relatively fast growth and ability to withstand environmental fluctuations. Crustose lichens, such as species of the genus Rhizocarpon, demonstrate exceptional longevity, with some individuals surviving for decades and even exceeding a century in optimal conditions **(Jahns, 2007)**. These growth and lifespan characteristics underscore the importance of lichens as stable and persistent components of ecosystems, providing continuous microhabitats and contributing to long-term soil and substrate stabilization.

1.1.8 Lichen Systematics and Classification

The classification of lichens has traditionally relied on the external form of the thallus, which represents the visible structure resulting from the symbiotic association between a fungal component (the mycobiont) and a photosynthetic partner, either green algae or cyanobacteria. Based on these structural characteristics, lichens have long been grouped into different morphological types. However, recent studies have shown that similarities in thallus form do not always indicate close evolutionary relationships. Instead, these forms often arise as adaptive responses to environmental conditions, reflecting convergent evolutionary processes rather than true phylogenetic relatedness among species. **(Martin Grube ,2007)**

1.1.8.1 Classification According to Thallus Morphology

a. Crustose

Crustose lichens develop as a thin crust firmly attached to the substrate, which makes their removal difficult without damaging the underlying surface. In this type of lichen, a lower cortex and rhizines are generally absent, and the thallus remains directly in contact with the substrate such as rock, bark, or soil. This structural organization allows crustose lichens to tolerate harsh environmental conditions, particularly drought and mechanical stress. As a result, they are frequently observed in exposed habitats, including arid areas and rocky surfaces where environmental conditions are often extreme. **(Michael Lakatos ,2006)**

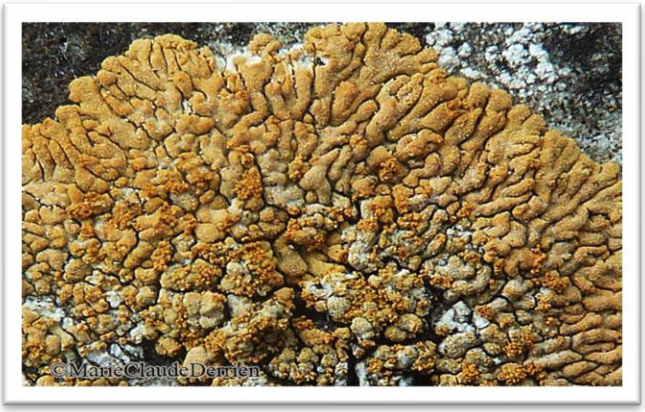


Figure 10. crustacean thallus **(Marie, 2015)**

b. Squamulose

Squamulose lichens represent an intermediate morphological form between crustose and foliose types. They are characterized by small scale-like lobes, known as squamules, which are generally loosely attached to the substrate. These squamules may group together to form cushion-like structures on the surface. In some genera, this type of thallus can also act as an initial stage that later gives rise to more developed lichen structures. This morphology facilitates the colonization of rocky substrates while allowing a certain flexibility and expansion across the surface. **(Lidia S, 2024)**



Figure 11. Squamulose thallus **(Lidia S, 2024)**

c. Gelatinous

Gelatinous lichens are generally characterized by a dark appearance and a gelatinous consistency when they are hydrated **(Ozenda & Clauzade, 1970)**. In moist conditions, their thalli expand and form gelatinous lobes or layers that may be more or less divided. These structures are often associated with algae or cyanobacteria within the thallus. However, when

the thallus dries, it loses its gelatinous texture and becomes more rigid and brittle **(Déruelle & Lallemant, 1983).**



Figure 12. Gelatinous thallus (*Lathagrium auriforme)* **(ANAB,2018)**

d. Foliose

Foliose lichens are characterized by a thallus resembling small leaves, composed of an uppercortex and a lower cortex separated by a medullary layer that contains the photobiont cells. The thallus is generally attached to the substrate by rhizines that originate from the lower cortex. This differentiated structure improves gas exchange and facilitates water retention more effectively than in crustose lichens. Consequently, foliose lichens are commonly found in relatively humid environments. The stratified internal organization also reflects an advanced level of structural integration between the fungal and photosynthetic partners. **(Grube, M., & Wedin, M. ,2016)**

e. Fruticose

Fruticose lichens are distinguished by a three-dimensional thallus that may appear shrubby, filamentous, or pendulous. Their growth form can be erect, prostrate, or hanging depending on the species and environmental conditions. The thallus often contains a central axis or a hollow medullary region surrounded by a cortical layer, while the photobiont cells are usually arranged in a peripheral zone. This structural organization increases the surface exposed to light and air movement while reducing self-shading. As a result, fruticose lichens are particularly efficient in capturing atmospheric moisture and nutrients from the surrounding environment. **(Porada, P., & Giordani, P,2021).**



Figure 13. Foliose thallus (*Lobaria pulmonaria*, on an alder trunk, a few minutes after a spritzing of water**. (Nelson,2021)**



Figure 14. Fruticose thallus *(Usnea filipendula)* **(Rouleau,2020)**

f. Leprose

Leprose lichens consist of tiny granules, typically ranging from 0.1 to 0.2 mm in size, forming a powdery thallus that can easily detach from the substrate (**Van Haluwyn *et al*., 2009).** These lichens are usually found in sheltered microhabitats, such as rock overhangs or bark crevices, where they are protected from direct rainfall **(Sérusiaux *et al.*, 2004**). Common genera exhibiting this leprose morphology include Lepraria and Chrysothrix **(Van Haluwyn *et al*., 2009)**



Figure 15. Leprose thallus **(Gérault,2018.)**

1.1.8.1 Classification Based on the Fungal Component

Lichen-forming fungi are primarily members of the phylum Ascomycota, while only a limited number of species belong to the Basidiomycota. Within Ascomycota, the evolution of lichenization has occurred independently multiple times across different classes, with the most significant radiations found in Lecanoromycetes, Eurotiomycetes, and Dothideomycetes. Notably, Lecanoromycetes alone account for nearly three-quarters of all described lichen-forming fungal species, highlighting its central role in the diversification and ecological success of symbiotic fungi **(Lumbsch & Leavitt, 2011; Honegger, 2008).**

1.1.9 Lichen Ecology

Lichens are found throughout the world, from arid deserts to polar regions, where some species can survive extreme cold down to -40 °C **(Larson, 1978)**. They act as pioneer organisms, establishing themselves on bare substrates and producing some of the first organic matter, which helps initiate local food webs **(Lipnicki, 2015)**. Lichens are able to grow on solid rock or desert soil and tolerate wide fluctuations in temperature, moisture, and drought conditions **(Richardson, 2002)**. When they die, their decomposition contributes to the formation of a thin soil layer that allows mosses and higher plants to colonize **(Aubert *et al.*, 2007).**

Based on the substrate, lichens are classified into several types **(Van Haluwyn *et al.*, 2009)**:

- Saxicolous lichens: grow on rocks, walls, or roofs, and adhere strongly to their substrate, sometimes being partially or fully incorporated into it.

- Terricolous lichens: develop on soil or humus, remaining entirely at the surface, commonly found in grasslands, fields, and dunes.
- Epiphytic lichens: live on the bark of trees or shrubs without harming the plant.
- Lichenicolous lichens: grow on other lichens.
- Muscicolous lichens : grow on mosses.
- Lignicolous lichens: grow on dead or slightly decayed wood, often in humid or shaded habitats.
- Foliicolous lichens : colonize leaves.

In all cases, lichens do not act as parasites; they simply use plants or other substrates as a support while obtaining nutrients from the air and light.

1.1.10 Lichens as Environmental Proxies

Lichens are widely recognized as effective environmental proxies because their biology and physiology make them extremely responsive to changes in the atmosphere. These organisms are symbiotic associations between a fungal partner (mycobiont) and a photosynthetic partner (photobiont, which can be algae or cyanobacteria). Unlike vascular plants, lichens lack a protective cuticle and true roots, obtaining all their water and nutrients directly from the air and precipitation. This direct contact with atmospheric inputs allows them to reflect environmental conditions with high sensitivity. **(Shukla *et al*, 2013)**

Because of their slow growth, extended lifespan, and ability to accumulate airborne substances over time, lichens can be used both for spatial assessments of pollution and for historical reconstruction of environmental quality. The role of lichens as bioindicators has been validated in a variety of ecosystems and pollution scenarios worldwide. In urban areas, for example, studies have shown that lichen species composition often mirrors air quality gradients. Research conducted in Munich, Germany, demonstrated that nitrogen dioxide (NO_2) levels strongly shape the composition of epiphytic lichens, while structural traits of host trees influence overall lichen diversity. **(Sebald *et al* ,2022)**

1.1.11 Economic and Applied Uses of Lichens

1.1.11.1 Food Applications

Lichens have also found applications in animal nutrition. In Nordic countries, for example, Cetraria islandica has been traditionally fed to pigs, horses, and cattle **(Ozenda, 2000).** In addition, lichens are regularly processed into flour, which offers a satisfactory energy value and

can be used in baking or in the preparation of bread suitable for diabetic diets **(Souchon, 1971)**. In Japan, several species of Umbilicaria are consumed either raw, as part of salads, or cooked in fat **(Hans, 1989).**

1.1.11.2 Medicinal and Pharmaceutical Uses

Lichens have been utilized in traditional medicine for several centuries, serving as remedies for a variety of ailments **(Karagöz *et al*., 2009)**. Indigenous communities in India as well as practitioners of traditional Chinese medicine have long relied on different lichen species for their therapeutic properties (**Richardson, 1988).** Among these, species of Usnea were particularly valued for their antimicrobial and anti-inflammatory effects. Cetraria islandica (Iceland moss) has been widely employed to treat respiratory conditions, including pulmonary diseases and catarrh, due to its soothing and mucilaginous properties **(Shukla *et al*., 2010)**. In India, Peltigera canina is traditionally consumed as a remedy for liver disorders, likely linked to its high content of the amino acid methionine, which may contribute to its presumed hepatoprotective effects **(Hale, 1983)**. Contemporary research has confirmed that numerous secondary metabolites produced by lichens possess significant medicinal potential, including antibiotic, antifungal, and antioxidant activities **(Pearce, 1997)**. In particular, several lichen metabolites have demonstrated notable activity against Gram-positive bacteria, although they generally show limited effects against Gram-negative species **(Shukla *et al.*, 2010)**. These findings underscore the enduring relevance of lichens as a source of bioactive compounds in both traditional and modern pharmacology.

1.1.11.3 Industrial Applications

The industrial use of lichens in the perfume industry relies mainly on two fruticose species collected from trees: Evernia prunastri *(oak moss*) and Pseudevernia furfuracea (tree moss). Each year, approximately 8,000 to 9,000 tons of these lichens are harvested for the production of traditional fragrances such as “Chypre” and “Russian Leather” (**George, 1999).** These lichens contain complex aromatic compounds that contribute both to the characteristic scent of the perfumes and to their ability to fix other fragrance molecules, enhancing longevity. Because these species grow slowly and are sensitive to environmental conditions, sustainable harvesting methods are essential to maintain their populations and ensure long-term availability. The economic value of fruticose lichens highlights their importance not only in perfumery but also in considerations of biodiversity and forest ecosystem management.

1.2 The study area

1.2.1 Geographical location of Mila region

The Wilaya of Mila is located in northeastern Algeria at an average altitude of approximately 464 meters and about 33 km from the Mediterranean Sea. It lies within the eastern part of the Tellian Atlas, a mountain range extending from west to east across the northern region of the country.

Geographically, Mila is bordered by several neighboring provinces: Jijel to the northwest, Constantine to the northeast, Sétif to the west, Skikda and Constantine to the east, Oum El Bouaghi to the southeast, and Batna to the south (Figure 16) The Neogene sedimentary basin of Mila is situated roughly 50 km northwest of Constantine and occupies the central part of the Wilaya. This basin is surrounded by mountainous and hilly formations: to the north by the foothills of the Tellian Atlas, including Sidi Driss (1364 m) and M'cid Aïcha (1462 m); to the east by carbonate reliefs such as Djebel Khreng, Djebel Akhal, and Chettaba; and to the south by Djebel Osman and Djebel Grouz. **(Melek & Djouambi, 2020)**

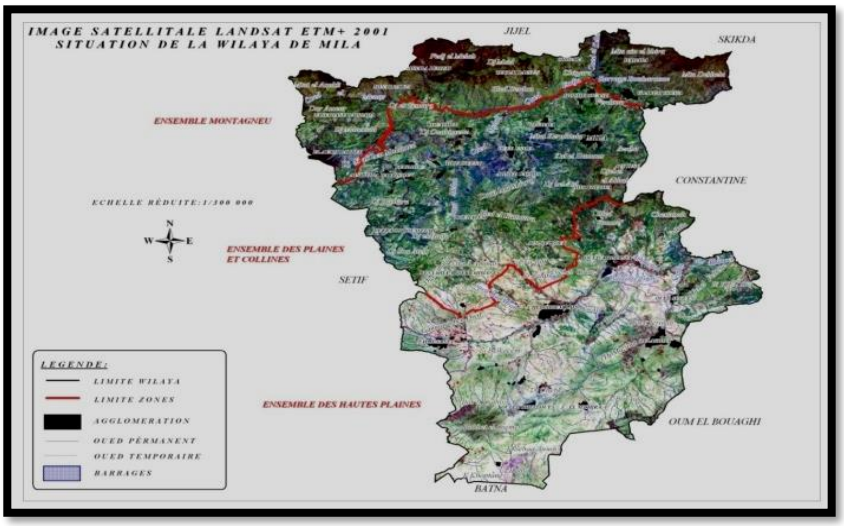


Figure 16. Map of the situation in the wilaya of Mila **(GDF Mila)**

1.2.2 Climate Characteristics

The Wilaya of Mila, located in northeastern Algeria, experiences a semi-arid Mediterranean climate characterized by significant seasonal variations and uneven distribution of precipitation. This climatic pattern influences both the natural environment and human activities in the region

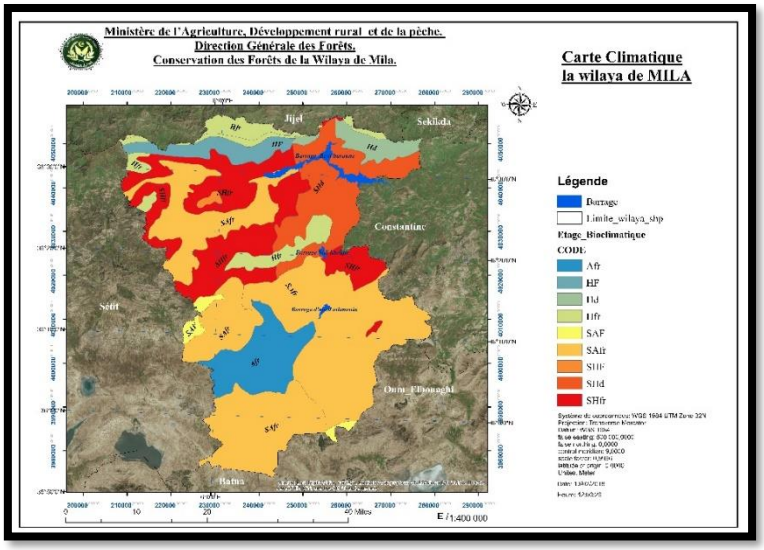


Figure 17. Climate map of the wilaya of mila **(GDF Mila)**

1.2.2.1 Temperature

Figure 18 illustrates the monthly temperature pattern recorded in Mila throughout the year. Temperatures remain relatively moderate during the winter season, with averages close to 10°C in January and February. From March onward, temperatures gradually rise, reaching their maximum during July, where the average exceeds 31 °C. This increase reflects the hot summer conditions that characterize the region. After the summer period, temperatures progressively decrease from September until December, when average values fall to nearly 13 °C. These seasonal thermal variations indicate the strong influence of a Mediterranean climate marked by hot, dry summers and mild winters.

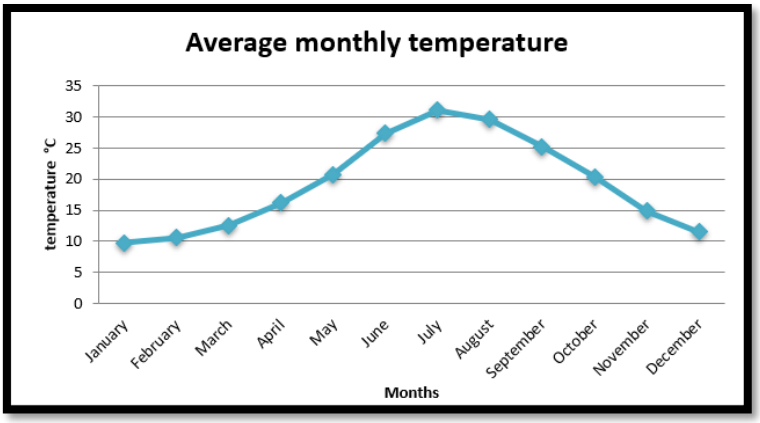


Figure 18. The monthly average temperature in Mila between (2015-2025)

1.2.2.2 Humidity

Representing the atmospheric moisture levels, the chart "figure 19" outlines the monthly humidity recorded in Mila, displaying a strong inverse relationship with temperature and sunshine hours. The year opens with high, stable humidity levels during the winter season (January, February, and March) fluctuating between 80% and 85% due to cooler temperatures and precipitation. From the beginning of spring, the curve plunges rapidly through April, May, and June, reaching its absolute minimum in July at around 50%. As summer concludes and autumn sets in, humidity levels climb steadily once again from September onward, peaking in December at nearly 90%.

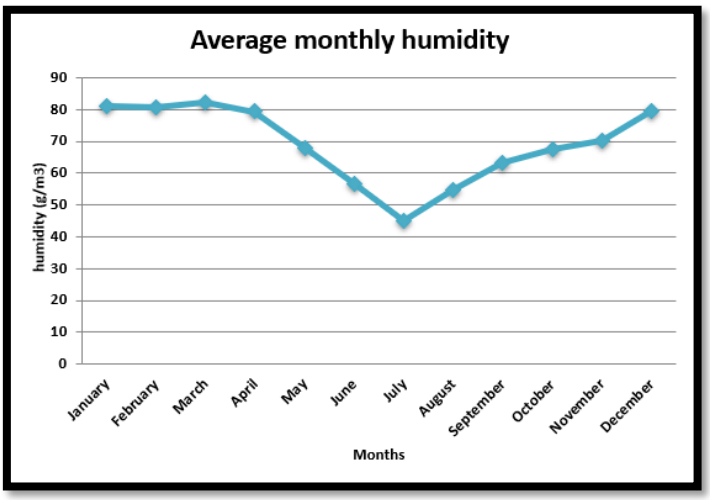


Figure 19. The monthly average humidity in Mila between (2015-2025)

1.2.2.3 Precipitation

The chart "figure 20" illustrates the monthly precipitation patterns in the Mila region throughout the year. The rainfall regime displays two distinct peaks; the first occurs at the beginning of the year in January (near 64%), rising to its highest annual level in March at over 65%. Conversely, the period from June to August undergoes a sharp drop in rainfall, hitting its lowest point in July at under 10%, which clearly demonstrates the region's characteristic summer drought. With the onset of autumn, atmospheric disturbances gradually resume, leading to a secondary autumn peak in November at over 50% before dropping slightly in December.

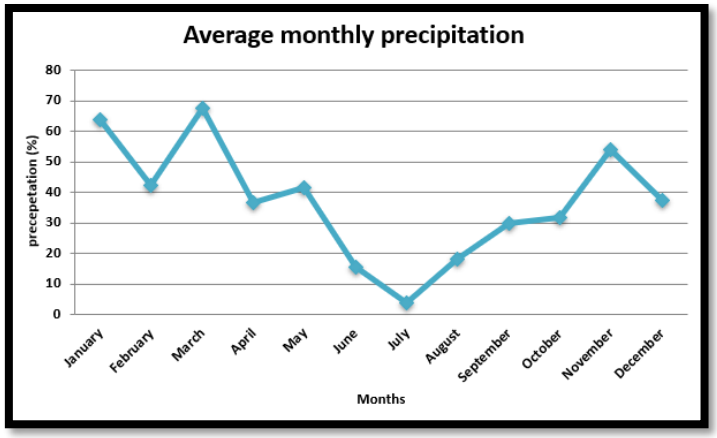


Figure 20. The monthly average of precipitation in Mila between (2015-2025)

1.2.2.4 Sunshine Duration

The graph "figure 21" reflects the monthly variations in daily sunshine hours across the province. The curve follows a steady upward trajectory starting from the winter months, where daily sunshine stands at around 10 hours in January and February, before progressively expanding through spring and summer. This duration reaches its absolute peak during May and June with an average of nearly 14 hours per day, driven by longer days and clear skies. Following this stable summer plateau, the curve begins a gradual descent at the start of autumn, with sunshine hours contracting to their lowest values in December at approximately 8 hours

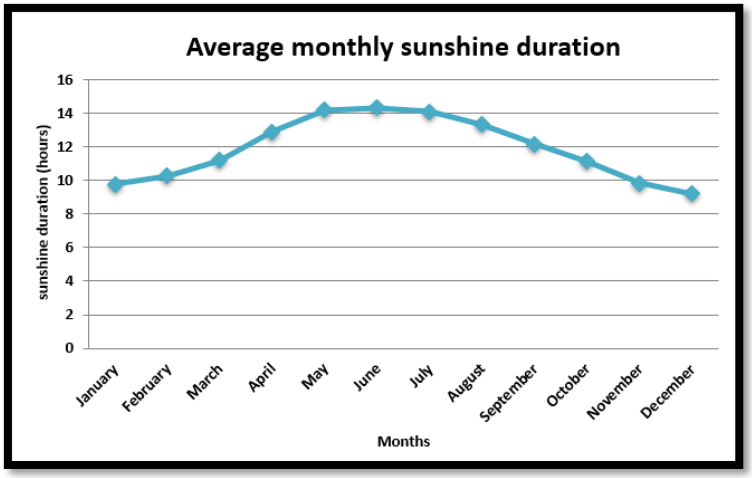


Figure 21. The monthly average sunshine duration in Mila between (2015-2025)

1.2.2.5 wind speed

The line graph presented in "figure22" provides a comprehensive overview of the average monthly wind speed measured in knots across the region over the course of the year. Wind activity is characterized by a relatively fluctuating yet moderate pace; the year opens with mild conditions in January (around 12 knots) before picking up noticeably in March to reach nearly 15 knots. After a slight easing during spring, the curve trends upward again through early summer to hit its maximum annual peak in July at an average of nearly 17 knots, which typically coincides with hot thermal updrafts. Between August and December, wind speeds progressively decelerate, stabilizing between 12 and 13 knots, despite a brief, minor resurgence in November

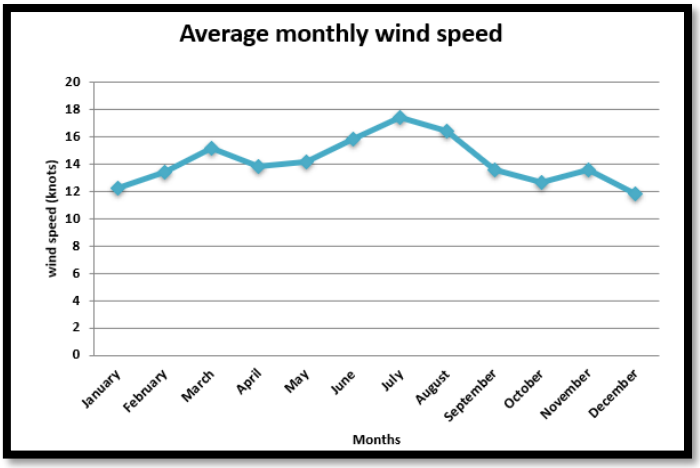


Figure 22. The monthly average of wind speed in Mila between (2015-2025)

1.2.3 Topographical Framework

The wilaya of Mila, located in the northeastern part of Algeria, is characterized by a remarkable topographic diversity that strongly influences natural dynamics as well as human activities. Its relief is structured around three main morphological units: mountainous areas, plains, and valleys **(MILA, 2019)**.

The mountainous landscapes, which form part of the Tellian Atlas, occupy a dominant position within the regional setting. They are characterized by varying elevations, sometimes steep slopes, and play a crucial role in the distribution of precipitation and the organization of the hydrographic network **(NICRS, 2018; WMO, 2021).** At lower elevations, valleys shaped by wadis provide relatively fertile lands that are suitable for agricultural development **(FAO, 2015).**

Furthermore, plains represent key areas for intensive agriculture and livestock farming due to their accessibility and generally more favorable soil conditions **(FAO, 2015)**. This

topographic configuration also influences the spatial distribution of population and infrastructure: plains and valley areas concentrate most human settlements and transport networks, whereas mountainous regions remain sparsely populated due to constraints related to accessibility and land development **(MILA, 2019).**

Thus, the topographic framework of the wilaya of Mila constitutes a determining factor in the territorial, economic, and social organization of the region.

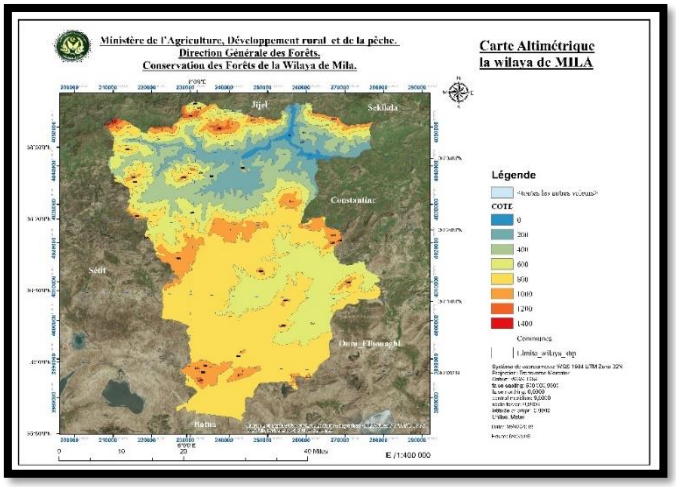


Figure 23. Altimeter map of the wilaya of Mila **(GDF Mila)**

Material and Methods



2. MATERIAL AND METHODS

2.1 Description of the selected sites

2.1.1 Site of Zwagha Bainan (Amira aras/tassala matai)

The Zouaghas forest plays an important ecological and socio-economic role within the region. It is mainly classified as a protection forest for the watershed of the Barrage de Beni Haroun, contributing significantly to soil conservation and water resource protection.

In addition to its environmental role, the forest also provides several forest products and secondary resources. Cork production represents one of the main economic activities, alongside the exploitation of fuel wood, diss, and caper plants

The Zouaghas state forest is located in the region of Mila in northeastern Algeria. Administratively, the forest extends over several municipalities belonging mainly to the districts of Terrai Bainen and Sidi Merouane, including Terrai Bainen, Amira Arres, Tessala Mettai, and Chigara**. (GDF Mila)**

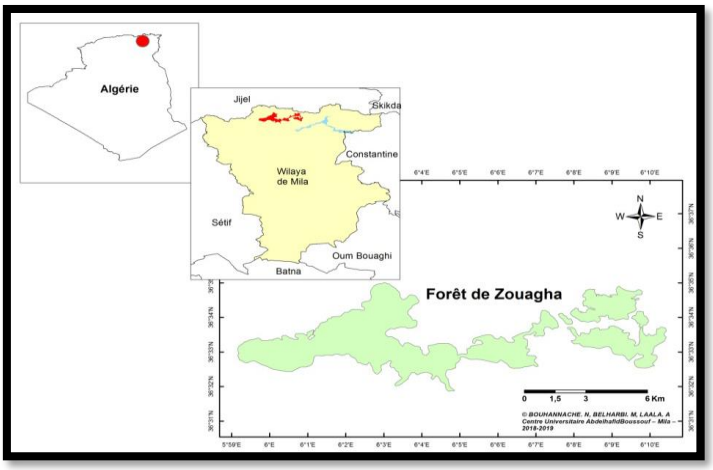


Figure 24. Geographical location map of the zwagha forest (**GDF Mila)**

The management and supervision of this forest area are ensured by the forest administration of Mila, particularly through the forest subdivision of Grarem Gouga and the forest districts of Terrai Bainen and Sidi Merouane. **(GDF Mila)**

Table 01 : Legal and administrative status of the zwagha forest **(DGF, 2018)**

The forest	Legal status	covernorate	district	region	sorting
zwagha	State forest	mila	Ghrarem gouga	-Tarei bainan -Sidi marouane	-tarei bainan -tassala lamtai -amira aras -al shigara

The study area belongs to the sub-humid bioclimatic stage. Annual rainfall ranges between 600 and 800 mm, while the average annual temperature is approximately 15 °C. The prevailing winds are mainly northwesterly, influencing both vegetation dynamics and ecological conditions within the forest ecosystem.

The forest is generally exposed toward the south and southeast. Geologically, the area belongs to the Numidian Mountain chain, characterized mainly by marl and sandstone formations. The slopes vary between 12.5% and 45%, while the maximum altitude reaches approximately 1354 m. These environmental characteristics strongly influence the distribution of vegetation and the ecological diversity of the region.

The vegetation cover of the Zouaghas forest is dominated by several Mediterranean forest species, particularly cork oak (*Quercus suber)*, zeen oak (*Quercus canariensis)*, and afares oak (*Quercus afares)*. The secondary vegetation mainly includes shrub species such as heather, calycotome, bramble, and lentisk. This floristic composition contributes to the ecological richness and biological diversity of the forest ecosystem**. (GDF Mila)**



Quercus suber



Quercus canariensis



Quercus afares

Photo 01. Predominant forest species of the zwagha forest **(personal photos.2023)**

The population of the surrounding area is estimated at approximately 67,013 inhabitants, with a population density of about 243.24 inhabitants/km². The dominant economic activities are mainly represented by the building and public works sector (46%), followed by other activities (44%) and agriculture (10%). These activities may exert varying levels of pressure on the forest environment and its natural resources. **(GDF Mila)**

2.1.1.2 Selection of Sampling Points and Number of Samples

The sampling points were selected in representative forest stands of cork oak (*Quercus suber*), zeen oak (*Quercus canariensis*), and Afarès oak (*Quercus afares*) in the stations of Amira Aâras and Tassala El Mtaâi. Accessible and representative areas were chosen for the establishment of transects.

In the Zawaga forest, a total of 45 trees were sampled using the stratified transect method along a transect line of approximately 150 meters.the sampling included 15 (*Quercus suber),* and 15(*Quercus canariensis)*, and 15 (*Quercus afares),* an interval of nearly 10 meters was maintained between the sampled trees

2.1.2. Site of Tamentout (Tessadane Haddada)

The Tamentout state forest is located in the northwestern part of the wilaya of Mila, between 36°29’51’’ and 36°34’15’’ North latitude, and between 5°44’11’’ and 5°56’12’’ West longitude.

This forest extends across the territories of three wilayas, namely Mila, Jijel, and Sétif. However, the present study focuses mainly on the northern part located within the territory of Mila. The forest is bounded to the south by the municipality of El Ayadi Barbes, to the north by the wilaya of Jijel, to the east by the municipality of Minar Zarza, and to the west by the municipality of Aïn Sebt. The total forest area is estimated at approximately 2801 hectares.

From an administrative and legal perspective, the Tamentout forest is managed by the forest administration of Mila through the forest subdivision of Ferdjioua and the forest district of Tassadane Haddada. It is classified as a state-owned forest. **(Ben Saleh,2022)**

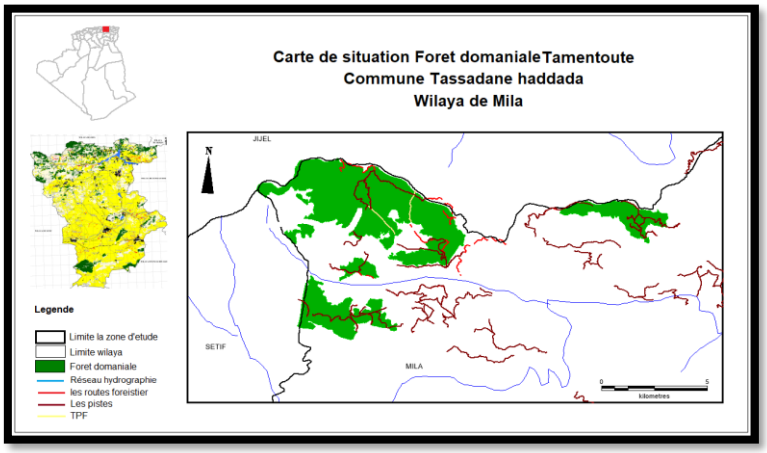


Figure 25. Geographical location map of the tamentout forest **(Ben Saleh,2022)**

Table 02 : Legal and administrative status of the tamentout forest **(Ben Saleh,2022)**

The forest	Legal status	covernorate	district	region	sorting
tamentout	State forest	mila	ferjiwa	-tasadan hddada	-tasadan hddada

The Tamentout forest belongs to a mountainous area mainly characterized by sandstone and interstratified limestone formations. The geological structure is dominated by clay formations dating from the Miocene period, which play an important role in groundwater formation and circulation.

The clay layers intercalated within the Eocene formations are generally impermeable, thereby influencing the hydrological and soil characteristics of the region.

The relief of the forest is marked by rugged and mountainous topography. Slopes are generally steep and may exceed 45%, giving the area a highly uneven landscape. These topographical conditions strongly influence vegetation distribution and ecological diversity within the forest ecosystem.

The vegetation cover of the Tamentout forest is dominated by several Mediterranean forest species, particularly cork oak (*Quercus suber*), zeen oak *(Quercus canariensis*), and afares oak (*Quercus afares*). These tree species constitute the main forest formations of the region. **(Ben Saleh,2022)**



Quercus suber



Quercus canariensis



Quercus afares

Photo 02. Predominant forest species of the tamentout forest **(personal photos.2026)**

The understory vegetation is composed of a variety of shrub and herbaceous species that contribute to the floristic richness of the ecosystem. The most common species include tree heather (*Erica arborea*), calycotome (*Calycotome spinosa*), bramble (*Rubus fruticosus*), lentisk (*Pistacia lentiscus*), diss (*Scirpus sylvaticus*), cytise (*Laburnum anagyroides*), myrtle (*Myrtus communis*), asphodel (*Asphodelus cerasiferus*), and wild olive (*Olea europaea*).

This floristic diversity reflects the ecological importance of the Tamentout forest and its role in maintaining regional biodiversity. **(Ben Saleh,2022)**

The Tamentout forest shelters a relatively diverse fauna adapted to the forest and mountainous conditions of the region. The main recorded animal species include the wild boar (*Sus scrofa*), red fox (*Vulpes vulpes*), wolf (*Canis lupus*), striped hyena (*Hyaena hyaena*), partridge *(Perdix perdix*), tortoises (*Testudines*), and wild rabbit (*Oryctolagus cuniculus*). **(Belkhechouf,2022)**

2.1.1.2 Selection of Sampling Points and Number of Samples

Sampling points in the Tamentout forest were established in representative stands dominated by cork oak (Quercus suber), zeen oak (Quercus canariensis), and Afarès oak (Quercus afares), especially in the station of Tseddan Haddada

In the Tamentout forest, a total of 45 trees were sampled using the stratified transect method along a transect line of approximately 150 meters.the sampling included 15 (*Quercus suber),* and 15(*Quercus canariensis)*, and 15 (*Quercus afares),* an interval of nearly 10 meters was maintained between the sampled trees

2.2 materials and equipment

2.2.1 sampling tools

During the field surveys, the following materials and equipment were employed:

- A semi-wooden grid divided into five squares measuring 15 × 15 cm was used to estimate the percentage cover of lichens on the studied substrates.



Photo 03. Grid divided into five squares measuring 15 × 15 cm **(personal photos.2026)**

- A knife was used to collect lichen samples.



Photo 04. A knife **(personal photos.2026)**

- A GPS application installed on a smartphone was used to record the geographic coordinates of the inventoried trees.

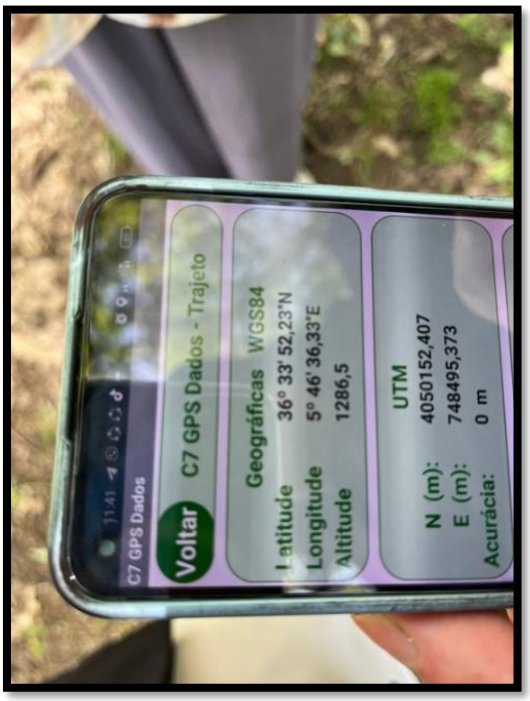


Photo 05. A GPS application installed on a smartphone **(personal photos.2026)**

- Plastic bags were used to preserve the moisture of the samples during transport from the field.



Photo 06. Plastic bags **(personal photos.2026)**

- A taxonomic identification key for lichen species determination, based on a modern reference such as Dobson, F. S. (2018).

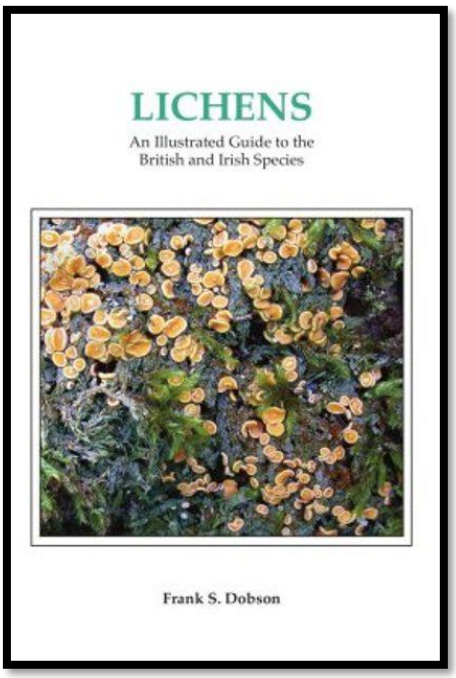


Photo 07. Guide of lichens **(personal photos.2026)**

- An iPhone 13 smartphone equipped with a high-resolution camera was used to take photographs during fieldwork.



Photo 08. An iPhone 13 smartphone (**personal photos.2026)**

- metric measuring tape was used to establish transects and maintain an approximate distance of 10 meters between sampled trees**.**



Photo 09. Ruban metrique **(personal photos.2026)**

- Lichen Sampling Data Sheet

site	nbr d'arbre	nom d'arbre	atitude	longitude	altitude(m)	nbr de cas	repartiton	nbr d'esp	nome d'esp
1	1	Quercus suber	36,323277	5,481258	857,77	1	60%	2	Xanthoria parietina
									Pertusaria sp
						2	70%	3	Xanthoria parietina
									Pertusaria sp
									Hypogymnia physodes
						3	90%	3	Xanthoria parietina
									Pertusaria sp
									Parmelia perlata
						4	80%	2	Xanthoria parietina
									Parmelia perlata
						5	90%	2	Parmelia perlata
									Pertusaria sp
	2	Quercus suber	36,323939	5,481816	851,76	1	40%	2	Xanthoria parietina
									Pertusaria sp
						2	60%	2	Xanthoria parietina
									Pertusaria sp
						3	70%	2	Xanthoria parietina
									Pertusaria sp
						4	90%	2	Pertusaria sp
									Parmelia perlata

Photo 10: lichen sampling data sheet **(personal photos.2026)**

2.3 Field Data Collection

Several field surveys were carried out in the study areas in order to inventory and collect lichen species.

In the forest of Zawaga, two field trips were conducted. The first survey took place on 19 April 2026 in the stations of Amira Aâras and Tassala El Mtaâi. These stations are mainly dominated by cork oak (Quercus suber), zeen oak (Quercus canariensis), and Afarès oak (Quercus afares). A second visit was carried out on 28 April 2026 in the same stations to complete the inventory and strengthen the sampling effort.

In the forest of Tamantout, the first survey was conducted on 21 April 2026 at the station of Tseddan Haddada, dominated mainly by cork oak (Quercus suber). Another field trip was carried out on 27 April 2026 in the same forest, targeting stands dominated by zeen oak (Quercus canariensis) and Afarès oak (Quercus afares).

2.4 Sampling Design and Data Collection

The sampling was carried out using a stratified transect sampling method. In each forest, a transect measuring approximately 150 meters was established. Along each transect, 15 trees were selected for lichen sampling, with a distance of nearly 10 meters between successive trees. This method allowed a regular distribution of sampling points inside each study site



Photo 11. Sampling Design for trees **(personal photos.2026)**

On every selected tree, lichen surveys were performed using a 15 × 15 cm grid placed at about 1.5 meters above the ground on the northern side of the trunk. The northern exposure was chosen because it generally provides more favorable microclimatic conditions for lichen growth, especially higher humidity and lower sunlight exposure



Photo 12. Sampling Design for lichen **(personal photos.2026)**

After observation and estimation of lichen cover, samples were carefully collected using a knife and placed in plastic bags to preserve their humidity during transportation to the laboratory. Each sample was photographed in situ before collection in order to facilitate later identification and documentation.



Photo 13. Data Collection of lichen **(personal photos.2026)**

2.5 Identification of Lichen Species

The collected lichen samples were identified using their morphological characteristics observed in the field and in the laboratory. Identification was based on the observation of color, thallus form, reproductive structures, and substrate type. And using the taxonomic guide of Dobson (2018)

Photographs taken during fieldwork were also used to support species identification and comparison with reference illustrations.

2.6 Biodiversity Assessment

The diversity of lichen communities was evaluated using ecological indices commonly applied in biodiversity studies. Species richness and abundance data obtained from the field surveys were used for the calculation of diversity indices

2.6.1 Species Richness

Species richness corresponds to the total number of species identified in a given study area. It is one of the simplest and most important indicators used to assess biodiversity.

$$S = N$$

Where:

N= total number of species

2.6.2 Frequency of occurrence

The relative frequency expresses the occurrence frequency of a species in relation to the total number of observations recorded in the study area. It is used to determine the distribution and occurrence level of lichen species within the sampled sites.

$$RO(\%) = \frac{ni}{N} \times 100$$

Where:

ni = number of occurrences of species i

N= total number of observations

2.6.3 Shannon–Wiever Index

The Shannon–Wiener diversity index was used to estimate the diversity of lichen species within each study site. This index considers both species richness and the relative abundance of species.

$$H' = -\sum_{I}^{S} Pi \log_2 pi$$

Where:

(H') = The Shannon–Wiener diversity index.

(S) = The total number of species in the community (richness).

(p{i}) = The proportion of individuals belonging to species

relative to the total number of individuals.

(ln) = The natural logarithm.

(Σ) = The sum of the calculations for all species

2.6.4 Equitability

Pielou's equitability index measures the regularity of species distribution within the community. Values close to 1 indicate a balanced distribution of species abundances.

$$J = \frac{H'}{Ln(s)}$$

Where:

H' = Shannon diversity index

S = total number of species

2.6.5 Simpson Index

The Simpson diversity index was also calculated to evaluate species dominance within the sampled communities.

$$D = 1 - \sum pi^2$$

Where:

(S) = Total number of species.

(p{i}) = Proportion of individuals belonging to species (i).

2.6.6 Jaccard Similarity Index

The Jaccard index is used to evaluate the similarity between two study sites based on the presence or absence of species. Higher values indicate greater similarity between the two forests.

$$J = \frac{a}{a + b + c} \times 100$$

Where:

a = number of common species between the two forests

b = number of species specific to the first forest

c= number of species specific to the second forest

2.7 Statistical Analysis

The collected data were organized and analyzed using standard statistical methods in order to compare lichen diversity between the studied forests and tree species. Tables and graphs were prepared to present the obtained results clearly.

Results



3. RESULTS

This chapter presenting the quantitative and qualitative data obtained from the field inventory of lichens in the forests of Bainan and Tamentout. The results are tabulated and presented in the form of statistical tables and ecological indicators aimed at describing the structure and distribution of the lichen communities. Specifically, the focus is placed on species richness, morphological characteristics, diversity indices (Shannon and Simpson), and a comparative analysis of the ecological similarity between the two sites

3.1 General characteristics of the study sites

The two studied forests, Baïnan Forest and Tamentout Forest, exhibit relatively similar ecological conditions, with some topographical differences that may influence the distribution of lichen communities.

Field surveys carried out in the study areas made it possible to characterize the main environmental parameters of the investigated sites, particularly the average altitude, geographical coordinates, and dominant forest species.

Table 03: General characteristics of the studied forests (bainan/tamentout

Parameter	Baïnan Forest	Tamentout Forest
Average altitude (m)	1012.07	1064.84
Average lichen coverage	35%	53%
Dominant species	*Quercus suber, Quercus afares, Quercus zeen*	*Quercus suber, Quercus afares, Quercus zee*
Vegetation type	Mediterranean forest	Mediterranean forest
Total number of lichen species	11	15

Figure 26 illustrates the comparison of the average altitude between Baïnan Forest and Tamentout Forest based on the field data collected during the study period.

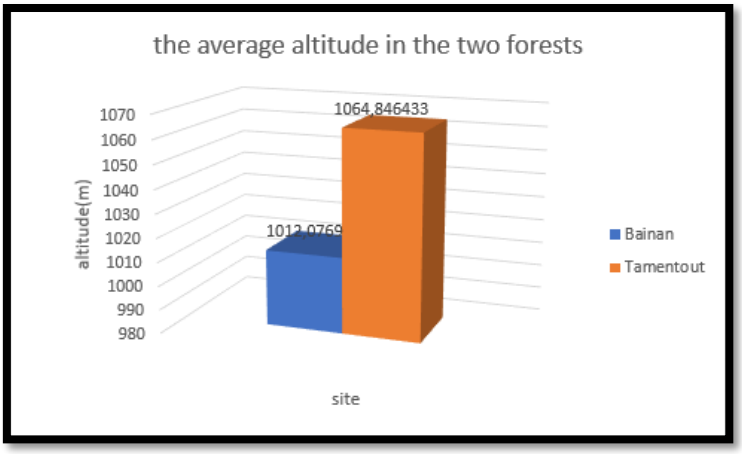


Figure 26. The average altitude between the two forests(bainan-tamentout)

The average lichen coverage differs between the two studied forests. Baïnan forest shows a mean coverage value different from that observed in Tamentout forest. These results are presented in Figure 27, which illustrates the comparison of mean lichen coverage between the two sites.

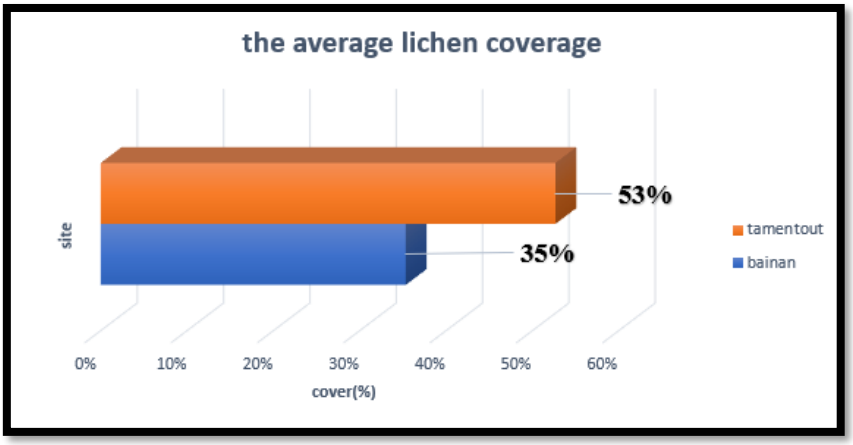


Figure 27. The average lichen coverage between the two forests(bainan-tamentout)

3.1.1 site 01

Table 04 presents the average altitude recorded for each tree species in Baïnan Forest. The results show variations in altitude among the sampled tree species.

Table 04: average altitude according to tree species in bainan forest

Tree species	Average altitude(m)
Quercus suber	1012.23
Quercus afares	1097.13
Quercus zeen	926.87

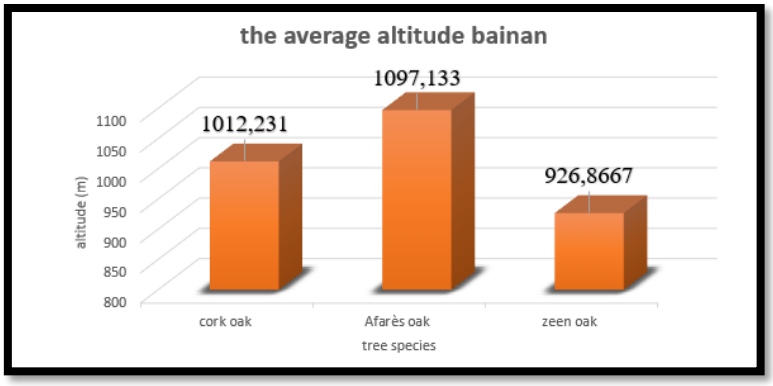


Figure 28. The average altitude of tree species in bainan forest

Table 05 shows the average lichen coverage observed on the different tree species in Baïnan Forest. Differences in coverage values were recorded among the studied host trees.

Table 05: average lichen coverage according to tree species in bainan forest

Tree species	Average lichn coverage (%)
Quercus suber	50%
Quercus afares	36%
Quercus zeen	20%

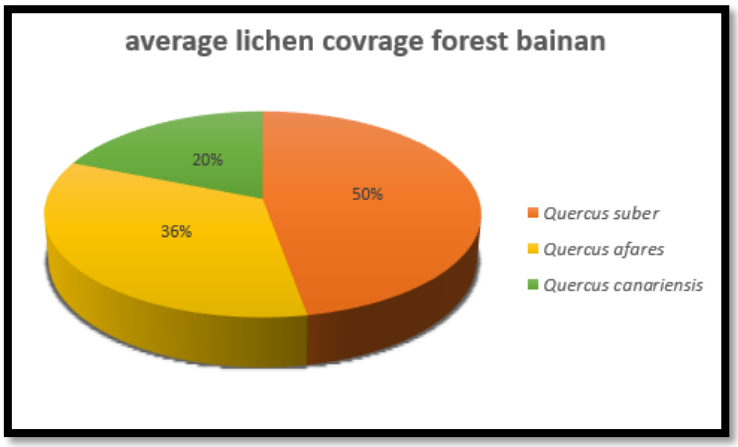


Figure 29. The average lichen coverage according to tree species in bainan forest

3.1.2 site 02

Table 06 presents the average altitude of the sampled tree species in Tamentout Forest. Variations in altitude were observed between the different tree species.

Table 06: average altitude according to tree species in tamentout forest

Tree species	Average altitude(m)
Quercus suber	868,9033
Quercus afares	1294,536
Quercus zeen	1031,1

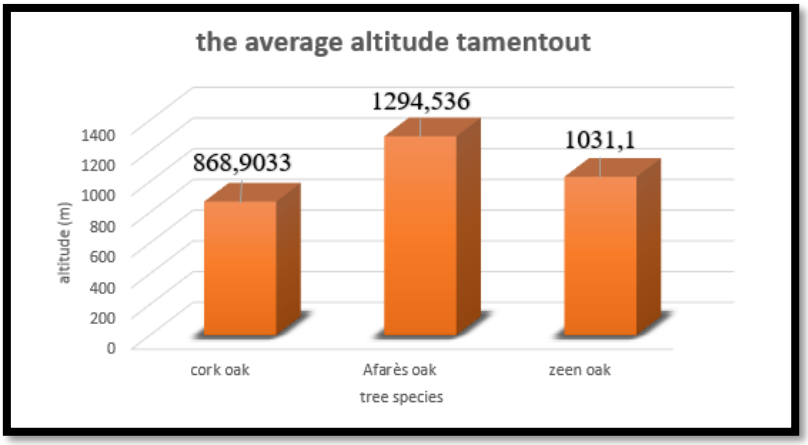


Figure 30. The average altitude of tree species in tamentout forest

Table 07 illustrates the average lichen coverage measured on the different tree species in Tamentout Forest. The results indicate differences in lichen coverage among the sampled host trees.

Table 07: average lichen coverage according to tree species in bainan forest

Tree species	Average altitude(m)
Quercus suber	46%
Quercus afares	93%
Quercus zeen	19%

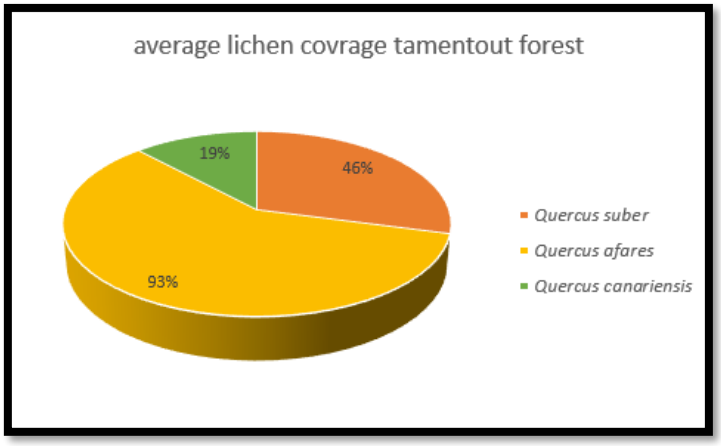


Figure 31. The average lichen coverage according to tree species in tamentout forest

3.2 Characteristics of the lichen species identified in the two sites

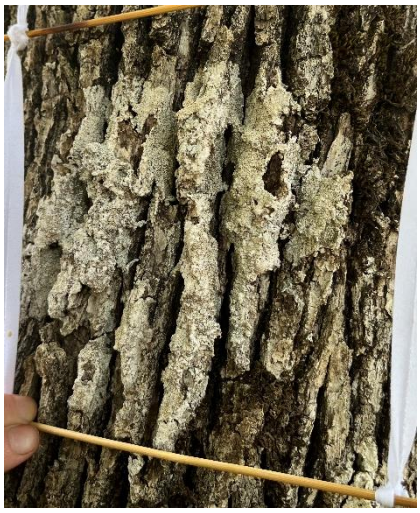
During this study, a total of 17 corticolous lichen species were identified. Table 04 presents the main characteristics of the lichen species recorded in the study area.

Table 08: Characteristics of the lichen species identified in the two forests(bainan-tamentout)

Photo	Species	Characteristics
	***Candelaria concolor***	Thallus small, foliose; forming large colonies, lemon yellow to mustard yellow. Habitat: corticolous on trees
	***Hypogymnia physodes***	Thallus foliose, gray to bluish gray, inflated lobes with black lower surface. Habitat: on tree bark.

	***Xanthoria parietina***	Thallus foliose, orange to bright yellow with many orange apothecia. Habitat: on bark and wood.
	***Parmelia perlata***	Thallus foliose, gray-green with broad lobes and white marginal cilia. Habitat: corticolous
	***Pertusaria sp***	Thallus crustose, gray to brownish with black immersed fruiting bodies. Habitat: bark and rocks.

	***Flavoparmelia caperata***	Thallus foliose, yellow-green, rosette-shaped with wrinkled surface. Habitat: on tree bark
	***Graphis scripta***	Thallus crustose, whitish-gray with black script-like lines. Habitat: corticolous.
	***Physcia adscendens***	Thallus foliose, gray-green with ascending lobe tips. Habitat: bark and rocks

	***Evernia prunastri***	Thallus fruticose, pale green, branched and flattened. Habitat: on trees.
	***Lepraria sp.***	Thallus powdery, thin, whitish to grayish. Habitat: bark, wood, and rocks.
	***Chrysothrix candelaris***	Thallus leprose, bright yellow with powdery appearance. Habitat: corticolous.

	***Parmelia sulcata***	Thallus foliose, gray-green with deeply furrowed surface. Habitat: on bark.
	***Ramalina sp.***	Thallus fruticose, branched, gray-green. Habitat: corticolous
	***Lobaria pulmonaria***	Thallus foliose, large, olive-green with perforated surface. Habitat: humid forests on trees

	***Lecanora sp.***	Thallus crustose, gray with round apothecia. Habitat: bark and rocks.
	***Melanelixia glabratula***	Thallus foliose, gray-brown with rhizines and brown apothecia. Habitat: corticolous.
	***Melanelixia subaurifera***	Thallus foliose, greenish-gray, wrinkled surface with brown apothecia. Habitat: on bark

3.3 taxonomic classification of the recorded lichen species

Table 09: Taxonomic classification of the lichen species recorded in bainan and tamentout forests

Class	Order	Family	Genus	Species
Locanoromycetes	*Lecanorales*	*Parmeliaceae*	*Hypogymnia*	*Hypogymnia physodes*
			Flavoparmelia	*Flavoparmelia caperata*
			Parmelia	*Parmelia sulcata*
				Parmelia perlata
			Evernia	*Evernia prunastri*
			Melanelixia	*Melanelixia glabratula*
				Melanelixia subaurifera
		Ramalinaceae	*Ramalina*	*Ramalina sp.*
		Candelariaceae	*Candelaria*	*Candelaria concolor*
		Lecanoraceae	*Lecanora*	*Lecanora sp*
	Caliciales	*Physciaceae*	*Physcia*	*Physcia adscendens*
	Teloschistales	*Teloschistaceae*	*Xanthoria*	*Xanthoria parietina*
	Graphidales	*Graphidaceae*	*Graphis*	*Graphis scripta*
	Pertusariales	*Pertusariaceae*	*Pertusaria*	*Pertusaria sp*
	Arthoniales	*Chrysotrichaceae*	*Chrysothrix*	*Chrysothrix candelaris*
	Peltigerales	*Lobariaceae*	*Lobaria*	*Lobaria pulmonaria*
	Lecanorales	*Stereocaulaceae*	*Lepraria*	*Lepraria sp*

3.4 Ecological indices

3.4.1 Species Richness

Species richness recorded in the two study sites is presented in Table 10. Tamentout Forest exhibited the highest richness with 15 species, whereas Baïnan Forest contained 11 species.

Table 10: species richness in the two study sites

Site	Species richness
Bainan	11
Tamentout	15

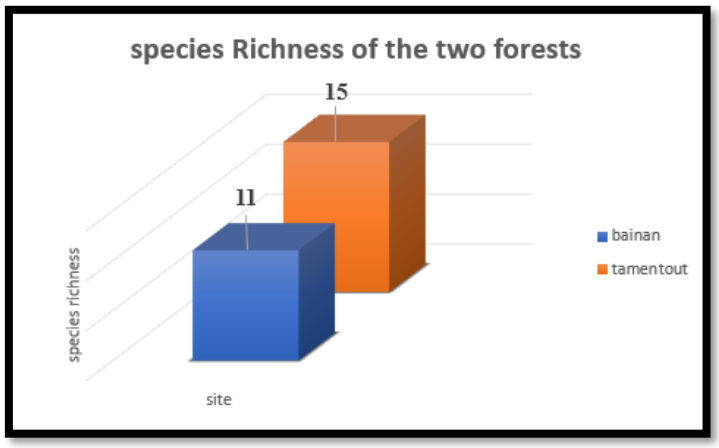


Figure 32. Comparison of species richness between bainan and tamentout forests

3.4.1.1 site 01

Species richness varied among the sampled tree species in Baïnan Forest. The highest value was recorded on *Quercus afares* (9), while the lowest richness was observed on *Quercus zeen* (3).

Table 11: species richness in the bainan forest

Tree species	Species richness
Quercus suber	6
Quercus afares	9
Quercus zeen	3

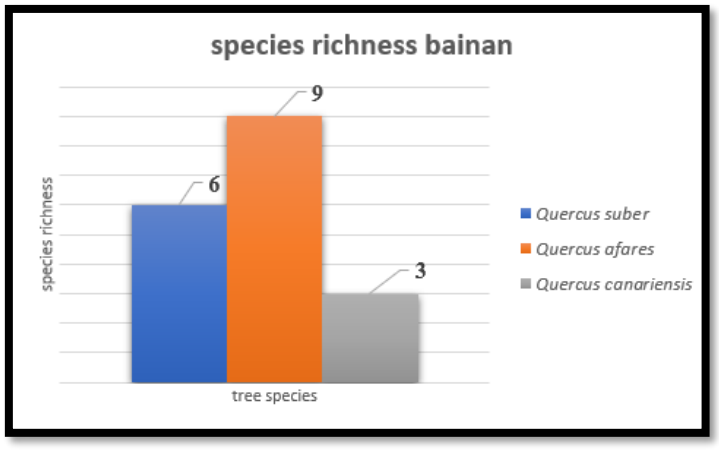


Figure 33. Species richness according to host tree species in bainan forests

3.4.1.2 site 02

The recorded species richness differed among the host tree species in Tamentout Forest. The highest richness was observed on *Quercus afares*, whereas *Quercus zeen* showed the lowest value.

Table 12: species richness in the Tamentout forest

Tree species	Species richness
Quercus suber	11
Quercus afares	12
Quercus zeen	4

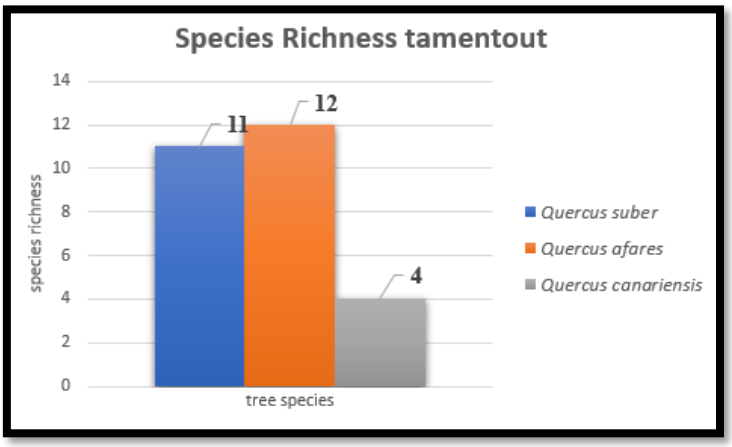


Figure 34. Species richness according to host tree species in tamentout forests

3.4.2 Frequency of occurrence

The frequency of occurrence values recorded in the two forests are presented in Table 13. Differences were observed in the distribution of lichen species between the study sites.

Table 13: frequency of occurrence in the two forests

species / site	Frequency of occurrence	
	bainan	tamentout
Candelaria concolor	3,56%	12,89%
Chrysothrix candelaris	1,78%	19,11%
Evernia prunastr	3,11%	8,00%
Lobaria pulmonaria	1,33%	28,44%
Locanora sp	6,22%	0,44%
Melanelixia subaurifera	0,89%	/
Parmelia perlata	12,44%	28,44%
Parmelia sulcata	8,00%	/
Pertusaria sp	41,33%	50,67%
Physcia adscendens	13,78%	8,00%
Xanthoria parietina	44,00%	4,44%
Melanelixia glabratula	/	1,78%
Hypogymnia physodes	/	0,44%
Lepraria sp	/	5,78%
Ramalina sp	/	10,67%
Graphis scripta	/	1,78%
Flavoparmetia caperata	/	1,78%

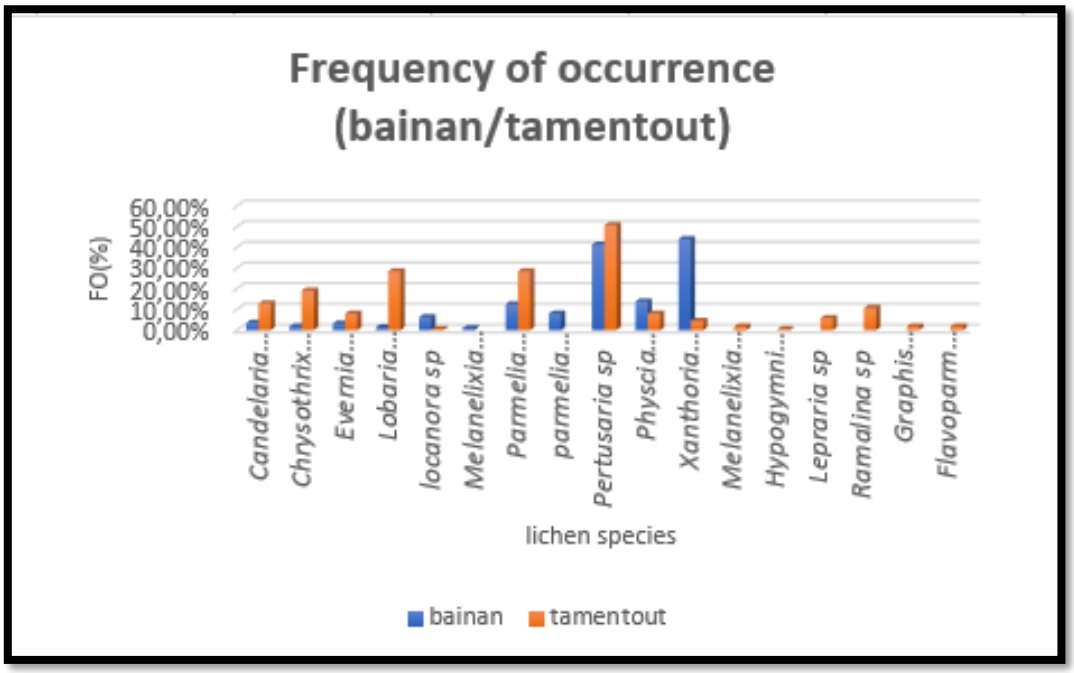


Figure 35. Frequency of occurrence, comparison between the two forests

3.4.3 shannon-wiever and Equitability

The Shannon-Wiener diversity index (H') and Pielou's equitability index (E) were calculated for the two study sites. As shown in Table 14, Tamentout Forest recorded higher values for both indices (H' = 2.1622; E = 0.7984) compared with Baïnan Forest (H' = 1.7996; E = 0.7505).

Table 14: shannon-wiever diversity index and equitqbility in the two study sites

Site	H’	E
Bainan	1.7996	0.7505
Tamentout	2.1622	0.7984

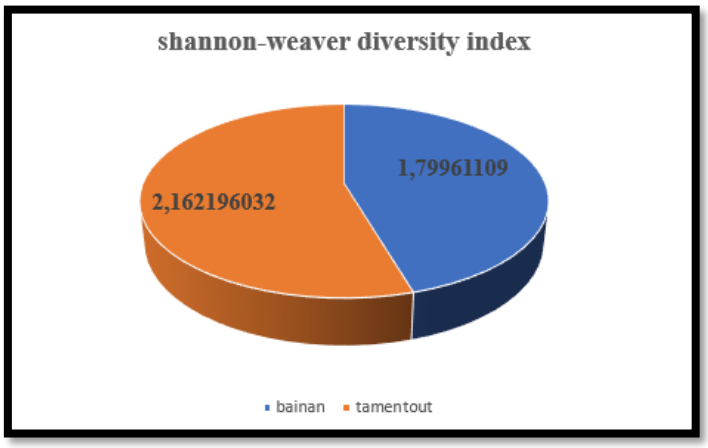


Figure 36. Comparison of Shannon-weaver diversity index between bainan and tamentout forests

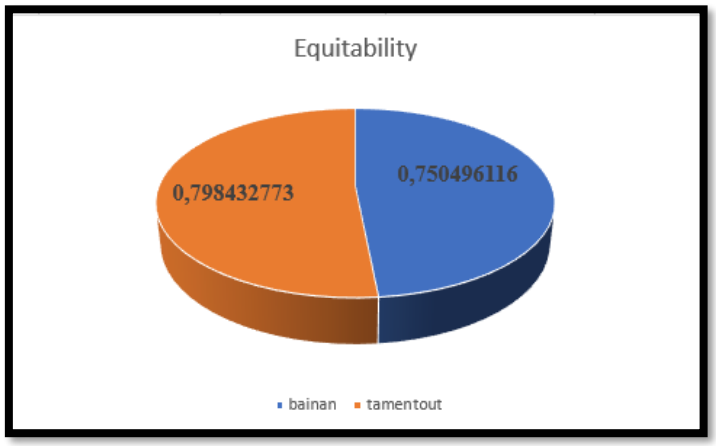


Figure 37. Comparison of Equitqbility between bainan and tamentout forests

Table 15 presents the Shannon-Weaver diversity index (H') and equitability (E) values calculated for the host tree species in Baïnan and Tamentout forests. In Baïnan Forest, the highest Shannon index was recorded on *Quercus afares* (H' = 1.7123), followed by *Quercus suber* (H' = 1.4726), whereas *Quercus zeen* showed the lowest value (H' = 0.9160). In

Tamentout Forest, *Quercus afares* also recorded the highest Shannon index (H' = 2.0219), followed by *Quercus suber* (H' = 1.9743), while the lowest value was observed on *Quercus zeen* (H' = 0.3358). The equitability values exhibited a similar pattern among the studied tree species in both forests

Table 15: shannon-wiever diversity index and equitqbility according to host tree species in the two sites

Index	H'		E	
Forest / Species	Bainan	Tamentout	Bainan	Tamentout
Quercus suber	1,472607506	1,974284965	0,821877898	0,82334078
Quercus afares	1,7122855	2,021850427	0,779294715	0,813652468
Quercus canariensis	0,915998189	0,335790947	0,833777483	0,242221967

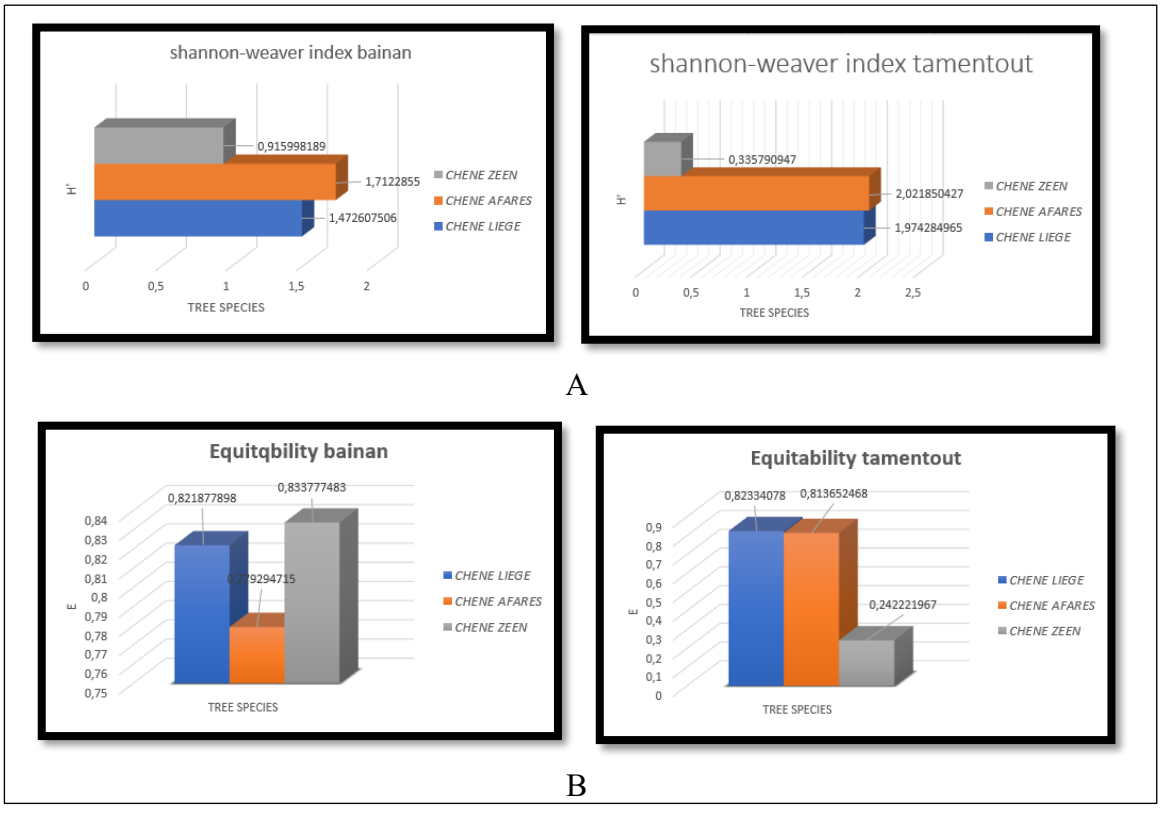


Figure 38. A: Shannon-weaver diversity index of site 01 et 02, B: Equitqbility index of site 01 et 02 all according to host tree species

3.4.4 simpson index

Table 16 presents the Simpson diversity index values calculated for the two study sites. Tamentout Forest recorded the highest value (0.8319), whereas Baïnan Forest showed a value of 0.7787.

Table 16: Simpson diversity index in the two study sites

Site	D
Bainan	0,778703222
Tamentout	0,849509534

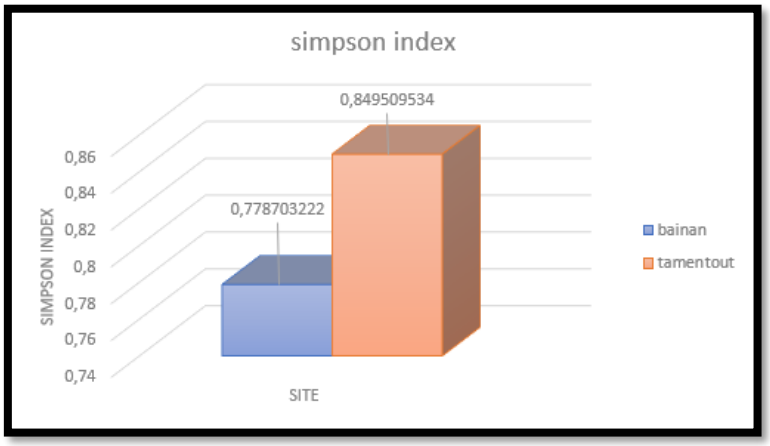


Figure 39. Comparison of simpson index between bainan and tamentout forests

Table 17 presents the Simpson diversity index values calculated for the host tree species in Baïnan and Tamentout forests. In Baïnan Forest, the highest Simpson diversity value was recorded on *Quercus afares* (D = 0.7658), followed by *Quercus suber* (D = 0.7215), whereas *Quercus zeen* showed the lowest value (D = 0.5510).

In Tamentout Forest, the highest value was recorded on *Quercus afares* (D = 0.841), closely followed by *Quercus suber* (D = 0.8319), while the lowest value was observed on *Quercus zeen* (D = 0.1360).

Table 17: simpson index according to host tree species in the two sites

Tree species / Site	D		
	Quercus suber	Quercus afares	Quercus zeen
Bainan	0,721527778	0,765805503	0,551039698
Tamentout	0,83191568	0,841267991	0,136054422

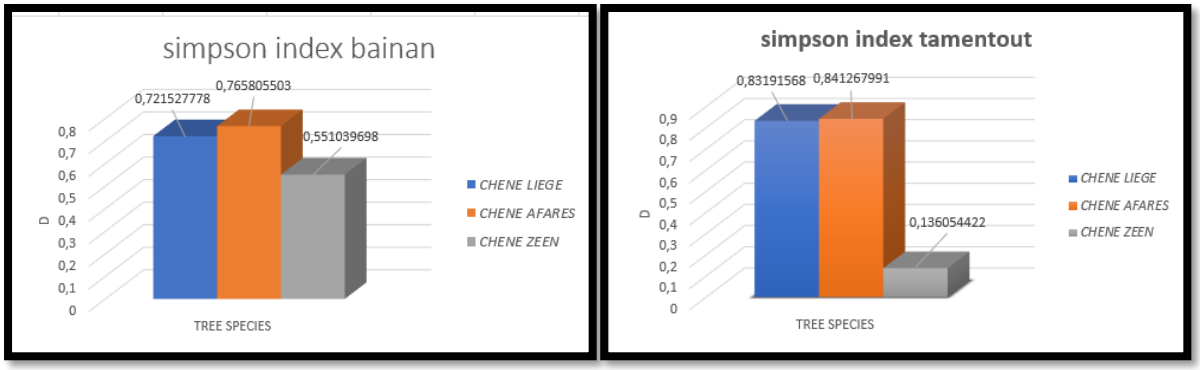


Figure 40. Simpson index according to trees species in bainan and tamentout forests

3.4.5 Jaccard Similarity Index

The Jaccard similarity index calculated between Baïnan and Tamentout forests was 0.52. This value indicates the existence of common lichen species shared between the two studied forests**.**

Figure 41 shows the distribution of common and non-common lichen species recorded in the two studied forests. A total of 9 common species and 8 non-common species were identified among the recorded lichens.

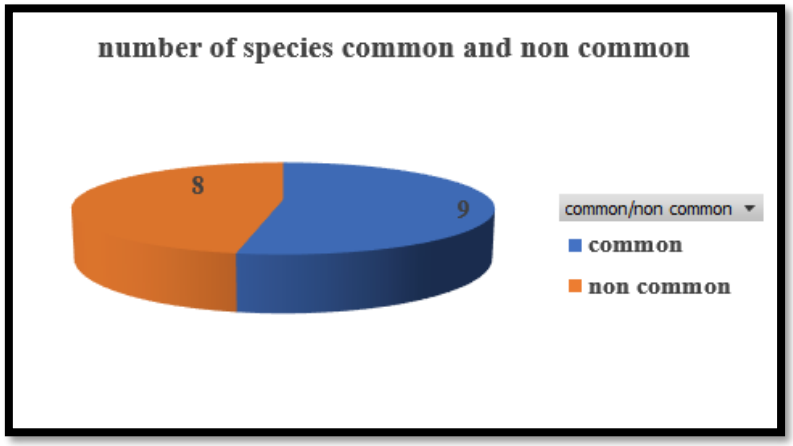
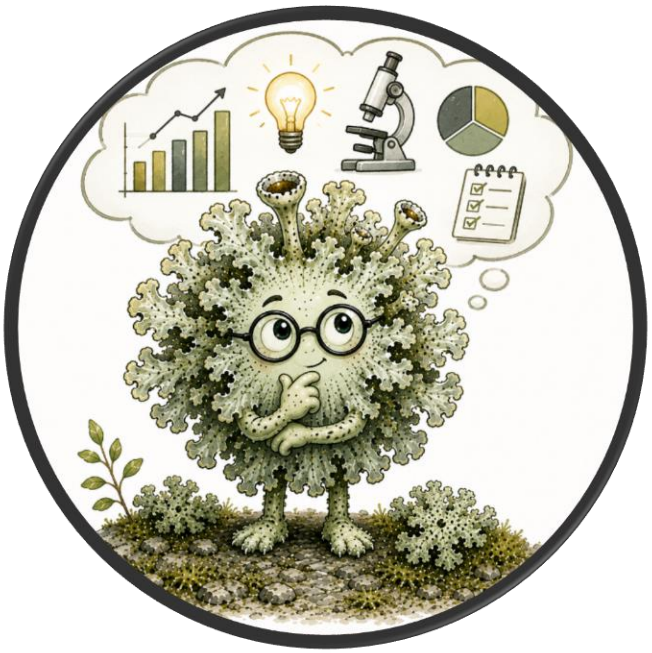


Figure 41. Distribution of common and non-common species between the two sites

DISCUSSION



4. DISCUSSION

Lichens are organisms of great ecological importance and are widely recognized as effective bioindicators for assessing environmental quality and ecosystem health. Their high sensitivity to atmospheric pollution, climatic variations, and substrate characteristics makes them valuable tools for monitoring ecological changes and biodiversity conservation **(Nimis *et al*., 2002; Nash, 2008).**

Numerous studies have demonstrated that the composition and diversity of lichen communities are strongly influenced by local ecological conditions, including climate, forest structure, tree species composition, and anthropogenic disturbances **(Purvis *et al*., 2004; Giordani, 2007)**. Consequently, the analysis of lichen species richness and diversity provides important information regarding the ecological status and conservation value of forest ecosystems.

In the present study, an inventory of lichens growing on tree bark was conducted in the forests of Zawaga and Tamantout to evaluate their diversity and distribution among different host tree species. The results revealed variations in species richness and diversity between the investigated sites. Such differences may be related to several ecological factors, including microclimatic conditions, substrate properties, and habitat characteristics, which are known to affect the establishment and development of lichen communities **(Nash, 2008; Brodo *et al*., 2001).**

The aim of this discussion is to interpret the obtained results through comparison with findings reported in previous studies and to highlight the principal ecological factors influencing lichen diversity and distribution within the two study sites.

The comparison between the two forests showed that the taxonomic analysis of the recorded species revealed a predominance of lichens belonging to the class *Lecanoromycetes*, which represented the majority of the taxa identified in both forests. This dominance is frequently observed in Mediterranean forest ecosystems and reflects the remarkable ability of this group to adapt to a wide range of environmental conditions. According to **Nash (2008)**, *Lecanoromycetes* constitute the most diverse group of lichens and occupy a broad spectrum of habitats due to their high ecological plasticity.

The inventory also revealed the presence of several important families, including *Parmeliaceae, Physciaceae, Ramalinaceae, Lobariaceae* and *Pertusariaceae*. Among them,

the family *Parmeliaceae* was the most represented, with species such as *Parmelia sulcata, Parmelia perlata, Flavoparmelia caperata, Evernia prunastri* and *Hypogymnia physodes*. This predominance may be explained by the ability of members of this family to efficiently colonize oak bark and tolerate the seasonal variations characteristic of the Mediterranean climate. Similar observations were reported by **Rabbas (2011)** and **Mohamed (2014)**, who recorded a strong representation of *Parmeliaceae* in several oak forests of northern Algeria.

The occurrence of species belonging to the families *Lobariaceae* and *Ramalinaceae* is also of particular ecological significance. Indeed, *Lobaria pulmonaria* and *Evernia prunastri* are generally considered demanding species that require high atmospheric humidity and good environmental quality. Their presence in the studied sites, particularly in Tamentout forest, confirms the relatively well-preserved nature of these forest ecosystems. According to **Van Haluwyn** and **Lerond (1993)**, these species are often used as bioindicators of air quality and forest ecological integrity.

Furthermore, the simultaneous occurrence of tolerant species such as *Xanthoria parietina* and sensitive species such as *Lobaria pulmonaria* reflects a certain degree of ecological heterogeneity within the studied sites. This functional diversity indicates the coexistence of microhabitats characterized by different environmental conditions, thereby promoting the establishment of species with varying ecological requirements. A similar phenomenon was reported by **Fadel (2018),** who emphasized that the diversity of forest microclimates is one of the main factors explaining the species richness of lichen communities.

Climatic factors play a fundamental role in determining the distribution and diversity of lichens within forest ecosystems. Among these factors, altitude is considered one of the most important because of its direct influence on temperature, humidity and precipitation patterns. The results of the present study showed that Tamentout forest, characterized by a higher average altitude (1064.84 m), exhibited greater species richness (15 species), higher lichen coverage (53%), and higher diversity index values compared to Baïnan forest, which is located at a lower average altitude (1012.07 m) and recorded only 11 species with a lichen coverage of 35%. These findings suggest that the environmental conditions prevailing in Tamentout are more favorable for lichen establishment and development.

This pattern can be explained by the fact that higher altitudes generally provide more suitable climatic conditions for lichen growth, particularly lower temperatures, higher relative

humidity and a longer persistence of moisture on tree bark following rainfall events or fog formation. Numerous studies have demonstrated that lichens depend heavily on atmospheric moisture because they absorb water and mineral nutrients directly from their surrounding environment without possessing true roots, making them highly sensitive to local climatic variations.

According to **Nash (2008)**, lichen diversity generally increases with altitude in humid forest environments as a result of improved microclimatic conditions and reduced water stress during dry periods. Similarly, **Ozenda** and **Clauzade (1985)** reported that mountain forests provide a greater diversity of microhabitats capable of supporting a wider range of lichen species, thereby enhancing species richness and promoting more balanced lichen communities.

the local climate within the forest plays an important role in explaining the differences observed between the two study sites. Forests characterized by dense vegetation cover tend to retain higher levels of humidity and reduce the effects of direct solar radiation and dry winds, creating favorable conditions for the establishment of sensitive lichen species. This may explain the occurrence of species such as *Lobaria pulmonaria*, *Evernia prunastri* and *Hypogymnia physodes*, which are commonly associated with humid and well-preserved forest environments. According to **Van Haluwyn** and **Lerond (1993),** the presence of these species often indicates stable climatic conditions and high environmental quality.

Moreover, the relationship between climate and lichens is not limited to humidity alone but also involves temperature and annual precipitation. High temperatures combined with low humidity levels can reduce the physiological activity and growth of lichens, whereas moderate temperatures and sufficient moisture promote colonization and expansion on tree bark. Therefore, local climate and altitude can be considered among the principal factors responsible for the higher lichen diversity, abundance and ecological stability recorded in Tamentout forest compared with Baïnan forest.

In addition to the ecological factors previously discussed, human presence in the vicinity of forest ecosystems may also influence lichen diversity and distribution. Forest areas located near human settlements are generally subjected to greater anthropogenic pressures, including wood collection, livestock grazing, agricultural expansion, and atmospheric pollution. These activities can modify habitat conditions and alter the microclimate required for the growth and persistence of lichen communities. Several studies have reported a decline in lichen richness

and diversity in areas exposed to intense human disturbance and air pollution, highlighting the sensitivity of lichens to environmental degradation (**Conti & Cecchetti, 2001; Giordani, 2007**). In contrast, forest stands that are less affected by human activities tend to maintain more stable environmental conditions, which favor the establishment and development of diverse lichen communities **(Nash, 2008).** Therefore, the proximity of local populations to the studied forests may partially explain the differences observed in lichen diversity, with lower anthropogenic pressure likely contributing to the higher ecological values recorded in Tamentout forest.

Lichen coverage is considered an important parameter for assessing the degree of substrate colonization by lichens and for evaluating the ecological status of forest ecosystems. The results of the present study revealed a clear difference between the two forests, with an average lichen coverage of 53% in Tamentout forest compared to only 35% in Baïnan forest. This difference reflects a greater capacity of lichen communities to establish and expand on tree bark in Tamentout forest and indicates the presence of more favorable conditions for their growth and development.

This result can be explained by the fact that lichen coverage is not only related to the number of species present but also to their ability to successfully colonize available substrates and increase their occupied surface area. Forest ecosystems characterized by ecological stability and suitable environmental conditions allow the gradual accumulation of lichen thalli over time, leading to higher coverage values. According to **Ozenda** and **Clauzade (1985)**, high lichen coverage is generally associated with stable habitats where natural and anthropogenic disturbances remain limited.

The results also showed considerable variation in lichen coverage among host tree species. *Quercus afares* exhibited the highest coverage value, reaching 93% in Tamentout forest, which represents the highest value recorded in this study. In contrast, the lowest coverage value was observed on *Quercus zeen* in Baïnan forest, with only 22%. These differences highlight the important role of bark characteristics in determining the ability of lichens to establish and expand. The bark of *Quercus afares* appears to provide more suitable conditions for lichen attachment and growth than the other tree species investigated.

These findings are consistent with those reported by **Fadel (2018)** and **Rabbas (2011),** who demonstrated that the abundance and coverage of corticolous lichens vary according to

host-tree characteristics and the degree of forest conservation. Therefore, the high lichen coverage recorded in Tamentout forest reflects not only a greater abundance of lichens but also the presence of favorable and stable environmental conditions. This interpretation is further supported by the higher species richness and diversity indices recorded in this forest.

The ecological indices calculated in the present study provide a comprehensive understanding of the structure, organization and ecological stability of lichen communities in the forests of Baïnan and Tamentout. Unlike simple species inventories, ecological indices make it possible to evaluate not only the number of species present but also their distribution, dominance patterns and degree of similarity between communities. Consequently, they constitute valuable tools for assessing biodiversity and environmental quality.

The analysis of species richness revealed clear differences between the two forests. Tamentout forest supported 15 lichen species, whereas only 11 species were recorded in Baïnan forest. Species richness is generally considered one of the simplest and most informative measures of biodiversity because it reflects the capacity of an ecosystem to provide suitable habitats for different organisms. The higher richness observed in Tamentout suggests that this forest offers a wider range of ecological niches and more favorable environmental conditions for lichen establishment. According to **Magurran (2004)**, species-rich communities are often associated with greater habitat heterogeneity and ecological stability. Similar observations were reported by **Rabbas (2011)** and **Mohamed (2014)**, who found that oak forests characterized by favorable ecological conditions generally harbor a larger number of lichen species.

In addition to species richness, the analysis of frequency of occurrence provided important information regarding the ecological behavior of the recorded species. The results showed considerable variation in frequency values among taxa. *Pertusaria sp*. was among the most frequent species in both forests, indicating a broad ecological tolerance and a strong capacity to colonize different substrates. In contrast, other species exhibited lower frequencies, suggesting more specific ecological requirements. The occurrence of highly frequent species generally reflects their ability to adapt to a wide range of environmental conditions, whereas species with restricted frequencies are often more dependent on particular habitat characteristics.

The frequency distribution also highlights differences in ecological preferences among species. *Xanthoria parietina* displayed relatively high frequencies, especially in Baïnan forest,

reflecting its well-known tolerance to environmental fluctuations. Conversely, species such as *Lobaria pulmonaria*, *Evernia prunastri* and *Hypogymnia physodes* showed a more restricted distribution and were mainly associated with favorable habitats. According to Van Haluwyn and **Lerond (1993)**, sensitive lichen species usually exhibit lower frequencies in disturbed environments and become more abundant in well-preserved ecosystems. Therefore, the frequency patterns observed in this study provide additional evidence of the relatively good ecological quality of the investigated forests, particularly Tamentout.

The Shannon-Weaver diversity index further confirmed these differences. Tamentout recorded a value of H' = 2.1622, while Baïnan showed a lower value of H' = 1.7996. Shannon diversity combines information on both species richness and abundance distribution and is therefore considered one of the most reliable indicators of community diversity. According to **Magurran (2004)**, higher Shannon values reflect more complex ecological communities where resources are shared among a larger number of species. The value obtained in Tamentout indicates a diversified lichen community characterized by a relatively balanced distribution of species, whereas the lower value observed in Baïnan suggests a less diversified community structure.

The Simpson diversity index showed a similar trend. Values reached 0.8495 in Tamentout and 0.7787 in Baïnan. Because this index is strongly influenced by species dominance, the higher value recorded in Tamentout indicates that no single species dominates the community excessively. Instead, several species contribute significantly to community composition. Such a pattern is generally associated with stable ecosystems capable of maintaining diverse biological assemblages. In contrast, lower Simpson values often indicate stronger dominance and reduced ecological complexity.

The ecological significance of the Shannon and Simpson indices becomes even more evident when considered together with species richness and frequency data. The higher richness (15 species), higher Shannon value (2.1622) and higher Simpson value (0.8495) recorded in Tamentout collectively indicate that this forest supports a more diverse and ecologically balanced lichen community. In contrast, Baïnan, with only 11 species, a Shannon index of 1.7996 and a Simpson index of 0.7787, appears to host a less diversified community characterized by a more uneven distribution of species.

The similarity analysis based on the Jaccard index yielded a value of 0.52, indicating a moderate similarity between the two forests. This value suggests that although Baïnan and Tamentout share several common species, each forest also contains characteristic taxa that contribute to its ecological individuality. The presence of nine species common to both forests reflects the influence of similar Mediterranean environmental conditions. However, the occurrence of exclusive species in each site demonstrates the importance of local ecological factors in determining community composition.

According to **Kent (2012)**, intermediate Jaccard values generally characterize communities subjected to similar regional climatic conditions but influenced by local environmental variations. In the present study, differences in altitude, host-tree composition, lichen coverage and microclimatic conditions may explain the moderate similarity observed between the two forests. The Jaccard value of 0.52 therefore reflects both the ecological proximity and the ecological distinctiveness of the investigated sites.

Overall, the combined interpretation of species richness, frequency of occurrence and diversity indices clearly demonstrates that Tamentout forest supports a richer, more balanced and ecologically stable lichen community than Baïnan forest. The higher richness (15 species), greater lichen coverage (53%), higher Shannon diversity (2.1622) and higher Simpson diversity (0.8495) collectively indicate more favorable environmental conditions for lichen establishment and persistence. These results confirm the usefulness of ecological indices as effective tools for evaluating biodiversity and assessing the ecological quality of Mediterranean forest ecosystems.

The integrated analysis of the different ecological indices provides a comprehensive understanding of the status of lichen communities in the two studied forests. The consistency between the higher species richness, greater lichen coverage and elevated diversity indices recorded in Tamentout forest indicates the presence of a more structured and ecologically stable lichen community compared to Baïnan forest. These results reflect not only a greater abundance of species but also their capacity to establish, persist and coexist within the forest ecosystem without excessive dominance by a limited number of taxa. Such equilibrium is considered a fundamental characteristic of healthy ecosystems, as it promotes efficient resource utilization and enhances long-term ecological stability.



Furthermore, the presence of species with different ecological requirements, ranging from tolerant taxa to sensitive species typically associated with well-preserved habitats, suggests the existence of diverse microhabitats within the studied forests. This environmental heterogeneity provides suitable conditions for a wider range of lichen species and contributes significantly to the overall diversity of the lichen community. These observations confirm that lichen distribution is not controlled by a single environmental factor but rather by the interaction of multiple factors, including host-tree characteristics, humidity, vegetation cover and local climatic conditions.

Moreover, the moderate similarity observed between the two forests indicates that belonging to the same biogeographical region does not necessarily result in identical species composition. Although several species were shared between the two sites, the presence of species restricted to a single forest highlights the influence of local ecological conditions on lichen distribution. This finding emphasizes the importance of microenvironmental factors in shaping biological communities, even within geographically close areas.

Based on the overall results obtained in this study, it can be concluded that Tamentout forest provides more favorable conditions for lichen establishment and development than Baïnan forest. This is reflected in the higher values recorded for the different ecological parameters. The results also confirm the importance of lichens as effective bioindicators of forest ecosystem quality due to their high sensitivity to environmental changes and their ability to accurately reflect ecosystem conditions. Consequently, the conservation of these forest ecosystems is of particular importance for maintaining the lichen biodiversity and ecological integrity of the region.

CONCLUSION



CONCLUSION

At the end of this study devoted to the assessment of corticolous lichen diversity in the forests of Baïnan and Tamentout (mila region), it was possible to establish a floristic inventory that provided valuable information on the lichen diversity occurring in these two forest ecosystems. The survey resulted in the identification of 17 corticolous lichen species distributed among 14 genera, 8 families, 7 orders and a single class, *Lecanoromycetes*, which represented the dominant taxonomic group in all the studied sites. This diversity highlights the ecological importance of these forests as suitable habitats for numerous lichen species, particularly those associated with Mediterranean forest ecosystems.

The taxonomic analysis revealed the predominance of several families commonly found in Mediterranean forests, including *Parmeliaceae, Physciaceae, Ramalinaceae* and *Lobariaceae*, confirming the influence of local environmental conditions on lichen distribution and establishment. The study also recorded species of high ecological significance such as *Lobaria pulmonaria*, Evernia prunastri and *Hypogymnia physodes*, which are known for their sensitivity to environmental disturbances and atmospheric pollution. Their presence reflects a relatively satisfactory environmental quality within the studied forests, especially in Tamentout forest.

The results revealed clear differences between the two forests in terms of species richness and lichen coverage. Tamentout forest supported a greater number of species and exhibited a higher lichen coverage than Baïnan forest, indicating more favorable environmental conditions for lichen establishment and development. These differences can be explained by the combined influence of several ecological factors, particularly altitude, local climatic conditions and host-tree characteristics. Among the investigated tree species, *Quercus afares* proved to be the most suitable host for lichen colonization, recording the highest values of species richness and diversity. This finding highlights the importance of bark characteristics in shaping the distribution and composition of lichen communities.

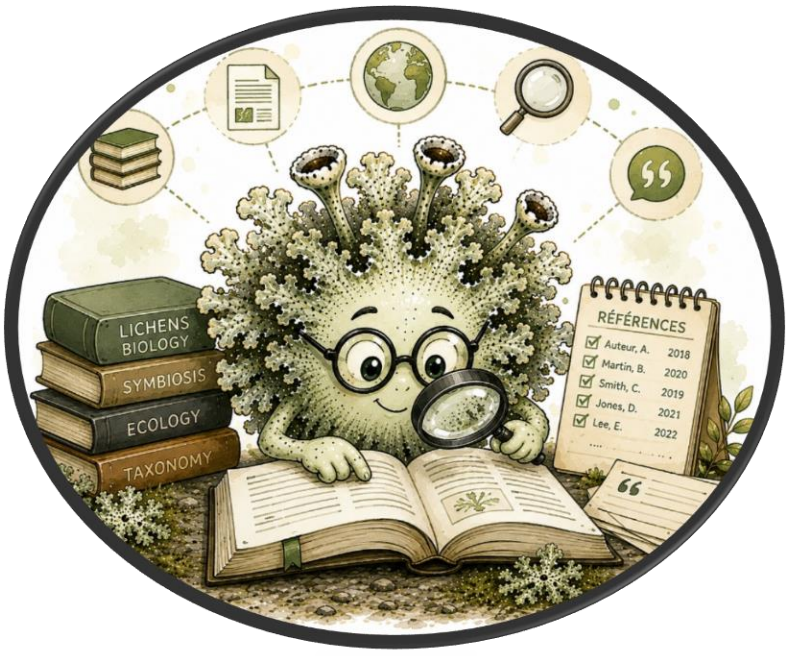
The study also confirmed the important role of climatic factors, especially altitude and humidity, in influencing lichen diversity and abundance. Tamentout forest, located at a relatively higher altitude, appears to provide more favorable conditions for lichen growth due to lower temperatures, higher relative humidity and more stable microclimatic conditions. Such environmental characteristics are known to promote the establishment of sensitive species and contribute to increased biodiversity within lichen communities.

Furthermore, the ecological indices calculated in this study confirmed significant differences in the structure and organization of lichen communities between the two forests. The results showed that the lichen community in Tamentout forest is characterized by higher levels of diversity, equilibrium and ecological stability than that of Baïnan forest. This reflects a greater capacity for species coexistence without excessive dominance by a limited number of taxa, indicating environmental conditions that are more favorable for the maintenance and development of lichen communities. Similarity analyses also revealed a floristic relationship between the two forests due to their location within the same biogeographical region, while each forest retained its own ecological particularities resulting from local factors such as altitude, humidity and host-tree characteristics. Taken together, these findings suggest that the recorded lichen diversity reflects a relatively good ecological status, particularly in Tamentout forest, and emphasizes the importance of these forest ecosystems for the conservation of local biodiversity.

Overall, this study demonstrates that the diversity of lichens in the investigated forests is controlled by a combination of environmental and biological factors, including climatic conditions, altitude, host-tree characteristics and habitat quality. The results also highlight the value of lichens as effective bioindicators for assessing forest ecosystem health and monitoring environmental changes. Moreover, the study emphasizes the ecological importance of oak forests in northeastern Algeria as natural reservoirs of biodiversity and essential habitats for numerous lichen species.

Finally, this work contributes to improving knowledge of the lichen flora of the mila region and northeastern Algeria. It also provides a scientific basis for future research focusing on the effects of climate change, atmospheric pollution and forest management practices on the dynamics and diversity of lichen communities, thereby contributing to the development of effective strategies for the conservation and sustainable management of these valuable forest ecosystems.

REFERENCES


LICHENS
BIOLOGY
SYMBIOSIS
ECOLOGY
TAXONOMY
RÉFÉRENCES
Auteur, A. 2018
Martin, B. 2020
Smith, C. 2019
Jones, D. 2021
Lee, E. 2022

REFERENCES

A

Ahmadjian, V., 1993. *The Lichen Symbiosis*. New York: John Wiley & Sons.

Ait Hammou, M., 2015. *Analyse taxonomique et écologique des lichens de la région de Tiaret*. Mémoire de recherche, pp. 1–18.

ANAB, 2018. *Lichens et champignons en interaction, épisode 6 : des fourmis cultivatrices (Lathagrium auriforme)* [Image/Article]. Available at: ANAB. Accessed 11 March 2026.

Aprile, G.G., Catalano, I., Migliozzi, A. and Mingo, A., 2011. Monitoring epiphytic lichen biodiversity to detect environmental quality and air pollution: the case study of Roccamonfina Park (Campania Region, Italy). In: *Air Pollution Monitoring and Assessment*.

Aquaportail, 2011. *Ascolichen* . Aquaportail Dictionary. Updated 28 February 2022. Available at: https://www.aquaportail.com/pictures2202/ascolichen.jpg (Accessed 9 March 2026).

Aubert, J., Fournier, B. and Henry, J., 2007. *Ecologie des lichens et des bryophytes*. Paris: Editions CNRS.

B

Boistel, P., 1986. *Les lichens et leur identification sur substrats rocheux*. Lyon: Presses Universitaires.

Brodo, I.M., Sharnoff, S.D. and Sharnoff, S., 2001. *Lichens of North America*. New Haven: Yale University Press.

Ben Saleh, Rehane., 2022. *Étude de la diversité spécifique de quelques subéraies de la wilaya de Mila*. Mémoire d'Ingénieur, École Nationale des Forêts, Batna, Algérie.

Belguidoum, A., Lograda, T., & Ramdani, M. (2022). *The lichen flora on Quercus in the Tamentout Forest of Algeria. Phytotaxa*, 566(2), 200–208.

Boucherma, M., & Abderzak, F. (2022). *Inventaire des lichens des secteurs Sud de la ville de Mila* [Mémoire de Master, *Centre Universitaire Abdelhafid Boussouf de Mila*].

Bendridi, B., & Rezaiki, M. (2022). *Contribution à l'étude de la flore lichénique des secteurs Nord de la commune de Mila* [Mémoire de Master, *Centre Universitaire Abdelhafid Boussouf de Mila*].

C

Collombet, J., 1989. *Ecology and Growth Dynamics of Lichens*. Paris: Masson.

Conti, M.E. and Cecchetti, G., 2001. Biological monitoring: lichens as bioindicators of air pollution assessment—A review. *Environmental Pollution*, 114(3), pp. 471–492.

D

Daoudi, I., 2016. *Flore lichénique de Mostaganem et analyses statistiques des données sur l'accumulation du plomb par Ramalina lacera (With.) Laundon*. Mémoire de Master, Université Abdelhamid Ibn Badis, Mostaganem, Algérie.

Déruelle, S. and Lallemant, R., 1983. *Les Lichens*. Paris: Presses Universitaires de France.

Direction de la Météorologie Nationale, 2019. *Annual Precipitation Report in Algeria*. Alger, Algeria.

Douibi, C., 2020. *Biodiversité lichénique de la région de Sétif et sa bio-indication dans la pollution atmosphérique*. Thèse de Doctorat, Université Ferhat Abbas, Sétif, Algérie.

E

Espace pour la Vie, n.d. *Lichens on Trees*. Jardin botanique de Montréal. Available at: https://espacepourlavie.ca/lichens-sur-les-arbres (Accessed 11 March 2026).

F

FAO, 2015. *Natural Resources Assessment in Algeria*. Rome, Italy.

Fadel, D., 2018. *Contribution à l'étude de la diversité lichénique dans le Parc National d'El Kala (Nord-Est algérien)*. Mémoire de Master.

Feuerer, T. and Hawksworth, D.L., 2007. Biodiversity of lichens, including a worldwide analysis of checklist data. *Biodiversity and Conservation*, 16, pp. 85–98.

Fontaine, K.M., Beck, A., Stocker-Wörgötter, E. and Piercey-Normore, M.D., 2012. Photobiont relationships and phylogenetic history of *Dermatocarpon luridum* var. *luridum* and related *Dermatocarpon* species. *Plants*, 1(2), pp. 39–60.

Friedl, T. and Büdel, B., 2008. Photobionts. In: T.H. Nash III (Ed.), *Lichen Biology*, 2nd ed. Cambridge: Cambridge University Press, pp. 9–25.

G

General Directorate of Forests, Mila 2026

Giordani, P., 2007. Is the diversity of epiphytic lichens a reliable indicator of air pollution? A case study from Italy. *Environmental Pollution*, 146(2), pp. 317–323.

George, E., 1999. Lichens and their role in the fragrance industry. *Journal of Natural Products*, 62(6), pp. 765–770.

Gérault, A., 2018. *Supralittoral Mesic Zone Lichens (Mesic Supralittoral Zone)*. Lichens marins – Marine and Maritime Lichens. Accessed 11 March 2026.

Gregory, S. and Dimijian, G., 2003. Global diversity and distribution of saxicolous lichens. *Journal of Lichenology*, 35(2), pp. 101–115.

Grube, M., 2007. Trouble with lichen: the re-evaluation and re-interpretation of thallus form and fruit body types in the molecular era. *Mycological Research*, 111, pp. 1116–1132.

Grube, M., 2015. La symbiose lichénique: un partenariat difficile à démasquer. *Frontiers in Microbiology*.

Grube, M. and Wedin, M., 2016. Lichenized fungi and the evolution of symbiotic organization. *Microbiology Spectrum*, 4(6), FUNK-0011-2016.

H

Hale, M.E., 1983. *The Biology of Lichens*. 3rd ed. London: Edward Arnold.

Hans, K., 1989. Edible lichens in Japan: traditional uses and culinary applications. *Journal of Ethnobiology*, 9(2), pp. 85–93.

Honegger, R., 1991. Functional aspects of the lichen symbiosis. *Annual Review of Plant Physiology and Plant Molecular Biology*, 42, pp. 553–578.

Honegger, R., 2008. Lichen-forming fungi and their photobionts. In: T.H. Nash III (Ed.), *Lichen Biology*. 2nd ed. Cambridge: Cambridge University Press.

Honegger, R., 2008. The lichen symbiosis—What is so spectacular about it? *The Lichenologist*, 40(3), pp. 233–236.

J

Jahns, H.M. and Henssen, A., 1973. Internal structure of lichen thalli: homoiomerous and heteromerous types. In: V. Ahmadjian and M.E. Hale (Eds.), *The Lichens*. New York: Academic Press, pp. 64–92.

Jahns, H.M., 2007. Longevity and ecological significance of lichen thalli. *The Lichenologist*, 39(4), pp. 287–297.

K

Karagöz, S., Akbulut, M. and Demirci, B., 2009. Traditional uses of lichens in medicine. *Journal of Ethnopharmacology*, 124(3), pp. 368–374.

Kent, M., 2012. *Vegetation Description and Data Analysis: A Practical Approach*. 2nd ed. Chichester: Wiley-Blackwell.

L

Lakatos, M., 2006. Functional characteristics of corticolous lichens in the understory of a tropical lowland rain forest. *New Phytologist*, 172(4), pp. 679–695.

Larson, D.W., 1978. Lichen survival in extreme environments. *Journal of Bryology*, 10(2), pp. 85–95.

Lipnicki, M., 2015. Pioneer organisms and ecosystem development: the role of lichens. *Ecological Studies*, 22(1), pp. 45–60.

M

Melek, K. and Djouambi, A., 2020. *Contexte géologique et richesse minière de la wilaya de Mila : apport économique et industriel pour la région*. Mémoire de Master, Université Mohammed Seddik Benyahia, Jijel, Algérie.

Ministry of the Interior and Local Authorities, 2019. *Monograph of the Wilaya of Mila*. Algiers, Algeria.

Magurran, A.E., 2004. *Measuring Biological Diversity*. Oxford: Blackwell Publishing

Mohamed, M., Khellaf, N., Rebbas, K. and Charef, N., 2014. Checklist and diversity of Algerian lichens. *Cryptogamie, Mycologie*, 35(4), pp. 377–398.

N

Nash, T.H. III (Ed.), 2008. *Lichen Biology*. 2nd ed. Cambridge: Cambridge University Press.

National Institute of Cartography and Remote Sensing, 2018. *Topographic Maps of Northeastern Algeria*. Algiers, Algeria.

Nelson, D., 2021. *Peltigera neopolydactyla* [Photograph]. 10,000 Things of the Pacific Northwest. Accessed 11 March 2026.

Nimis, P.L., Scheidegger, C. and Wolseley, P.A. (Eds.), 2002. *Monitoring with Lichens – Monitoring Lichens*. Dordrecht: Kluwer Academic Publishers.

O

Olivier, A., 2006. *Ecology of Saxicolous Lichens*. Paris: Éditions Scientifiques.

Ozenda, P. and Clauzade, G., 1970. *Les lichens : morphologie, écologie, systématique*. Paris: Masson.

Ozenda, P. and Clauzade, G., 1985. *Les Lichens: Étude Biologique et Flore Illustrée*. Paris: Masson.

Ozenda, P., 2000. *Flore et végétation de la France*. Paris: Masson.

P

Pearce, C., 1997. Lichen metabolites and their pharmaceutical potential. *Phytochemistry Reviews*, 1(2), pp. 95–107.

Porada, P. and Giordani, P., 2021. Bark water storage plays key role for growth of Mediterranean epiphytic lichens. *Frontiers in Forests and Global Change*, 4, Article 668682.

Purvis, O.W., 2000. *Lichens*. Washington, DC: Smithsonian Institution Press.

Purvis, O.W., Coppins, B.J., Hawksworth, D.L., James, P.W. and Moore, D.M., 1992. *The Lichen Flora of Great Britain and Ireland*. London: Natural History Museum Publications.

R

Rebbas, K., 2011. *Contribution à l'étude de la flore lichénique en Algérie*. Thèse de Doctorat, Université d'Annaba, Algérie.

Richardson, D.H.S., 1988. *Lichenology and Ethnopharmacology*. Berlin: Springer.

Richardson, D.H.S., 2002. *Lichen Biology*. 2nd ed. Cambridge: Cambridge University Press.

Rouleau, A., 2020. Lichens in Winter. *Hiver/Winter 2020–2021 Issue*. Accessed 11 March 2026.

S

Sebald, V., Goss, A., Ramm, E., Gerasimova, J.V. and Werth, S., 2022. NO_2 air pollution drives species composition, but tree traits drive species diversity of urban epiphytic lichen communities. *Environmental Pollution*, 308, Article 119678.

Sérusiaux, E., Diederich, P. and Lambinon, J., 2004. *Les macrolichens de Belgique, du Luxembourg et du Nord de la France*. Meise: Jardin Botanique National de Belgique.

Sérusiaux, E., van den Boom, P. and Diederich, P., 2004. Reproductive strategies in lichenized fungi. *Mycological Research*, 108(6), pp. 617–628.

Sérusiaux, E., van den Boom, P. and Diederich, P., 2004. Reproductive strategies and substrate preferences in lichens. *The Lichenologist*, 36(3), pp. 183–198.

Shukla, V., Upreti, D.K. and Bajpai, R., 2010. Medicinal properties of lichen secondary metabolites. *Journal of Medicinal Plants Research*, 4(12), pp. 1102–1110.

Shukla, V., Upreti, D.K. and Bajpai, R., 2013. Selection of biomonitoring species. In: *Lichens to Biomonitor the Environment*. New Delhi: Springer India, pp. 97–170.

Singh, S.P. and Sinha, S., 1997. Role of lichens in soil stability and microflora development. *Journal of Ecology and Environment*, 19(2), pp. 105–112.

Souchon, Y., 1971. *Les lichens et leur utilisation*. Paris: Éditions Lechevalier.

Spribille, T., Tuovinen, V., Resl, P., Vanderpool, D., Wolinski, H., Aime, M.C., Schneider, K., Stabentheiner, E., Toome-Hellmich, S., Thor, G., Mayrhofer, H. and McCutcheon, J.P., 2016. Lichens may be a symbiosis of three organisms. *Science*, 353(6298), pp. 488–492.

V

Van Haluwyn, C., Asta, J. and Gavériaux, J.-P., 2009. *Lichens de France*. Paris: Belin.

Van Haluwyn, C., Asta, J. and Gavériaux, J.-P., 2009. *Lichens de France : livre d'identification*. Paris: Belin.

Van Haluwyn, C., Sérusiaux, E. and Clerc, P., 2009. *Lichens : diversité et écologie*. Liège: Jardin Botanique de Belgique.

Van Haluwyn, C., Asta, J. and Gavériaux, J.-P., 2009. Échanges nutritionnels entre les partenaires des lichens (Figure 2).

W

Witts, J., 2023. *Exploitation of Lichens as a Source of Novel Natural Products*. Doctoral Thesis, University of Nottingham, United Kingdom.

World Meteorological Organization, 2021. *Climatic Data for Algeria*. Geneva, Switzerland.

World Meteorological Organization, 2021. *Climatological Normals for Algeria*. Geneva, Switzerland.

Y

Yakovchenko, L.S., 2024. *Candelariella ahtii (Candelariaceae, Ascomycota): A New Species of Lichen from Central and North-East Asia, and a Key to 8-Spored Candelariella*. *Phytotaxa*, 2024.

T

Theunis, L., 2023. Lichens: Bioindicators of Air Quality. *DailyScience.be*, 20 March 2023.