

Ethnic, economic, and therapeutic applications of lichens as a source of bioactive secondary metabolites: An integrative review

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Abstract: Interest in and research on lichens is increasing day by day due to their benefits to human health and their uses in various fields. This study aims to reveal the potential uses of lichens in human life, from traditional to modern, through a broad literature review. Producing many unique secondary metabolites as a result of their symbiotic lifestyle, lichens are among the natural resources used in various fields such as medicine, pharmaceuticals, cosmetics, chemical dyes, textiles, and the food industry. Their increasingly discovered biological effects—antifungal, antibacterial, antioxidant, antitumor, anticarcinogenic, and antiviral—highlight the significant potential of lichens in health biotechnology. Some lichens are known to provide habitat material and food for various animals and are also consumed by humans. Ethnic uses of lichens can be seen in mummification, traditional clothing, costumes, and ornaments in various cultures from ancient times to the present. Today, lichens are frequently encountered in artistic designs, accessories, floriculture, terrariums, and decorative wall hangings. Historical medical research has revealed various therapeutic uses of lichens. Many lichen species have been documented as sources of active pharmaceutical ingredients in medicines and as components of cosmetic products. Current studies on lichen extracts and lichen secondary metabolites indicate that lichen species exhibit antibacterial, antioxidant, antiviral, and antifungal activities, and have medical potential as therapeutic agents against a variety of diseases. This review briefly examines the biology and contributions of lichens to nature, followed by information on their versatile uses from various sources dating back approximately 80 years.

INTRODUCTION

Lichens play a vital role in natural ecosystems by contributing to processes such as soil formation and element cycles through their ability to survive in challenging environments with the unique secondary compounds they synthesize. In addition to their ecological roles, they have been used by humans in various ways for centuries. Many traditional communities have also used lichens for health, nutrition, and decorative purposes. Lichens continue to be recognized and increasingly important today for both their ecological importance and their potential to provide new natural products of diverse importance.

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This study focuses on presenting information on the historical development of lichens and their ethnological, economic, and medicinal uses in human life, by reviewing literature spanning approximately 80 years. Including brief introductory information on lichen biology, chemistry, and ecology, this review compiles and presents detailed and comprehensive information on the cultural and commercial uses of lichens in sectors such as medicine, pharmacy, cosmetics, food, agriculture, artistic design, paint, and chemistry, under separate headings.

A Brief Overview of Lichen Biology and Chemistry

Symbiotic associations of at least one alga and one fungal species (often hosting more species) form a lichen. In other words, the fungus collaborates with a photosynthetic species, resulting in the emergence of a lichen as a new organism, morphologically and physiologically transformed (Çobanoğlu, 2025; Nash, 2008). The fungal partner, most of which are from the *Ascomycetes* and a small portion from the *Basidiomycetes* and *Deuteromycetes*, provides carbon dioxide, water, and mineral substances to the lichen. The algal partner, from the *Chlorophyta* or *Cyanobacteria* group (mostly *Nostoc*, *Trebouxia*, or *Trentepohlia* genera), contributes to the symbiosis by taking in these substances and producing organic matter and oxygen through photosynthesis (Arun *et al.*, 2023). It is known that there are approximately 25,000 species of lichens in the world, which are systematically included in the kingdom of Fungi (Nash, 2008). Although lichens have plant-like characteristics due to their photosynthetic algal partners (photobiont), they are classified based on their fungal partners (mycobiont), which enable them to reproduce via sexual spores. Lichenization occurs through a transformation that has different properties from its symbiotic components and acquires its own biological and chemical characteristics. This symbiosis contributes significantly to the adaptation of lichens to environmental conditions by producing their unique metabolites on a genetic basis (Culberson & Culberson, 2001; Singh, 2023).

Approximately 1050 lichen metabolites have been reported, most of which are colorless acidic compounds that are insoluble in water but soluble in organic solvents (Stocker-Wörgötter, 2015). Some of these are colorful pigments that protect lichens from stress conditions. Continuing research is underway on the biosynthetic mechanism of lichen secondary metabolites. After the monosaccharides produced by the lichen photobiont are transferred to the mycobiont, the synthesis of lichen secondary compounds with different structures occurs via three main pathways: the Shikimic Acid Pathway, the Mevalonic Acid Pathway, and the Acetyl-Polymalonyl (Polyketide) Pathway (Ranković & Kosanić, 2019). The chemical groups involved in lichen secondary metabolites are mostly represented by depsides, depsidones, dibenzofurans, diphenylethers, pulvinic acid derivatives, quinones, xanthonones, and terpenes (Elix & Stocker-Wörgötter, 1996).

Habitat, Survival, and Adaptive Characteristics of Lichens

Lichens have a wide distribution on Earth, from the poles to deserts, because they can adapt to harsh habitats. The secondary metabolites they produce enable lichens to survive in extreme conditions as a means of chemical defense. They protect themselves against herbivores, parasites, and diseases (Sochting, 1999; Dayan & Romagni, 2001; Ranković & Kosanić, 2019) and UV radiation (Ndhlovu *et al.*, 2023; Solhaug *et al.*, 2003) with these compounds. Lichens can be found in all types of habitats in terrestrial ecosystems, such as alpine, forest, steppe, or seaside, from the equator to the poles, from mountain peaks to sea level (Brodo *et al.*, 2001). Since the growth rate of lichens is very slow (about 1-5 mm per year), they live in their environment for many years; It is stated that there are species estimated to be over 1000 years old (Nash, 2008). There are old lichens on the trunks and branches of trees, on rocks and historical monuments, and on the tiles of old buildings. Their dimensions give an idea about the duration of their presence in the substrate (Çobanoğlu, 2025). They are divided into three main groups, depending on the substrate they live on: epiphytic (trees), epilithic (rocks), and epigeic (soil) (Nash, 2008). With their root-like rhizine structures, they can also hold on to stones, soil, rocks, trees, mushrooms, wood, walls, concrete, tile-roofs, fabric, leather, furniture, plants, and

even lichens (Armstrong, 2017). Apart from this, we can also see lichens on man-made surfaces such as walls, historical artifacts, and gravestones (Figure 1).



Figure 1. Some examples of substrates on which lichens attach; from left to right, ceramic pottery, wall, tree bark, stone (photos belong to the authors).

Lichens, which are considered particularly sensitive to air pollutants, have been used in studies conducted over the last century to monitor air pollution levels, representing another area of their application (Nash & Gries, 1991; Seed *et al.*, 2013). The ability of certain species to survive in extreme conditions, such as mines and nuclear power plants, provides advantages for air quality measurement (Çobanoğlu, 2015). Lichens, which have a high tolerance to toxic and heavy metals, are frequently preferred and reliable biological tools in air quality biomonitoring studies. The continuity of lichen existence is important for biomonitoring to reveal the negative effects of poor environmental conditions and irregular population growth (Garty, 2001).

Food and Shelter Function of Lichens for Fauna

Lichens contribute to natural element cycles with their ecological role as photosynthetic producers in the food web. They provide habitat for many living creatures in natural life. They are used by invertebrate animals for shelter, nutrition, and hiding. Insects, spiders, moths, etc., use lichen thallus to hide and protect their larvae. Some invertebrates, snails, and slugs feed on *Lobaria*, *Parmelia*, *Physcia*, and *Xanthoria* species (Çobanoğlu, 2025). Many vertebrate animals such as deer, polar bear, mountain goat, sheep, cattle, antelope, squirrel, mouse, and bat are among the animals that eat lichen. *Bryoria* filamentous lichens are winter food and nesting material for flying squirrels, the main prey of spotted owls, in North Pacific forests (USDA, 2016). Birds have been observed building nests from lichens of the genera *Usnea*, *Lobaria*, and *Parmelia* (Seaward, 2008). Wild turkeys and forest chickens have also been recorded to feed on these lichens (Hayward & Rosentreter, 1994).

Lichen species with high nutritional value are harvested and used to feed reindeer in some polar regions and Scandinavia. *Cladonia rangiferina* and *Cetraria islandica* are among the species with high nutritional value (Seaward, 2008). Barbary macaque monkeys (*Macaca sylvanus*), living in fir forests in the high-altitude mountainous regions of Morocco, consume lichens in harsh winters. For snub-nosed monkeys of the genus *Rhinopithecus* in the high forests of the Himalayas, *Bryoria nepalensis* and *Usnea* species constitute the majority of their diet in winter (Matsuzawa, 2017).

DATA COLLECTION METHODOLOGY

This review presents the various uses of lichens from the past to present, primarily under separate headings: ethnic, economic, and medicinal uses. For this purpose, a detailed and comprehensive worldwide literature review was conducted, compiled from publications covering the years 1948-2025 on the secondary metabolites and biological activities of lichens and their use in different sectors such as paint, food, and pharmaceuticals. Search engines such as ScienceDirect, PubMed, Google Scholar, Scopus, EBSCO, Web of Science, ProQuest,

HighWire Press, Cochrane Library, and Current Literature on Lichens were used. The available information on commonly used lichen species, their activities, bioactive components, and possible mechanisms of action is comprehensively summarized and discussed. Lichen species and secondary metabolites with very good activity are highlighted. This review can serve as an updated, simplified reference to facilitate and guide future research on these unique natural products.

ETHNIC USES OF LICHENS

Ethnolichenology – Ethnic, Economic, And Medical Perspectives

Ethnolichenology is defined as the branch of science that examines how lichens are used for different purposes in human cultures (Brodo *et al.*, 2001). The traditional and modern uses of lichens have been the subject of numerous studies to date (Ali *et al.*, 2024; Dayan & Romagni, 2001; Llano, 1948). Lichens, which stand out for their interesting symbiotic life and are potential natural sources of bioactive secondary metabolites, have been widely used in many fields such as medicine, pharmacology, cosmetics, food, dye, chemistry, and textile from the past to the present. Many lichen species around the world have been used as drugs, food, natural dyes, and decorative materials in herbal treatments and for various ethnocultural purposes since ancient times (Dayan & Romagni, 2001). In the history of medicine, lichen-containing applications are encountered in prescriptions for treatment purposes (Elkhateeb *et al.*, 2022; Shah *et al.*, 2024; Yavuz & Çobanoğlu, 2010).

Mummification

The use of lichens in folk medicine dates back to the Ancient Egyptian Civilization. The most concrete evidence in this regard is B.C. It is a lichen sample identified as *Evernia furfuracea* (now known as *Pseudevernia furfuracea*), which was removed in 1859 from the chest of a mummy belonging to a woman, dated between 500-800 BC and probably named "Abothloé" (Abdel-Maksoud & El-Amin, 2011; Ranković & Kosanić, 2019; Schmull & Brown, 2009). It is also reported that this species was used in tobacco mixture and pipe production in ancient times (Broad, 1989).

In ancient Egypt, the lichen *P. furfuracea* was found in a vase with other medicinal plants from the 16th to the 14th centuries BC (Müller, 2001). During the New Kingdom (1549–1069 BC) and the Third Intermediate Period (1069–656 BC) in Egypt, lichens were used in the mummification process, in which corpses were stuffed with lichens and other plants (Schmull & Brown, 2009). At that time, *P. furfuracea* did not grow in Egypt because the country was too arid, so it is assumed that the lichens were probably the result of trade and came from Lebanon or the hills of Macedonia, although this has not been proven. In early modern Europe, a mixture of *E. prunastri* and *P. furfuracea*, known as the lichen *Quercinus virides*, became a popular medicine (Llano, 1948; Senft, 1911). Due to their appearance, both lichens are probably considered together, but their chemical composition is different.

Art and Decoration

Lichens, with their intricate morphology, natural hues, and ecological symbolism, have increasingly become valuable materials in modern art and decorative design. Their organic textures and long-lasting forms make them appealing for both traditional crafts and contemporary visual arts. Some lichen species (*P. furfuracea*, *E. prunastri*, *Cladonia* spp.) have been preferred instead of flowers or plants for home decoration, model making (in museums and building construction presentations), and to be placed on graves (Çobanoğlu, 2025; Devkota *et al.*, 2017). Some lichen species, such as *Cladonia*, have been used in decorative paintings, floristry, wreath making, terrariums, and accessories in recent years (Figure 2). Today, lichens are frequently included in current designs inspired by nature and are exhibited in contemporary works of art.

In earlier centuries, dried lichen specimens were incorporated into folk ornaments, grave adornments, and botanical displays, reflecting a cultural appreciation for natural resilience and permanence. Species such as *E. prunastri* and *P. furfuracea* were particularly preferred for their pleasant aroma, pliability, and preservation capacity (Devkota *et al.*, 2017; Llano, 1948).

In present-day design practices, lichens are used as eco-friendly decorative elements in floral arrangements, terrariums, and vertical garden panels. *C. rangiferina* and *P. furfuracea* are among the most popular taxa applied in “moss art” and bio-based interior architecture, providing both aesthetic and acoustic advantages while requiring no maintenance (Elkhateeb *et al.*, 2022). Their natural pigmentation and porous textures make them ideal for museum models, educational dioramas, and architectural prototypes (Seaward, 2008). Beyond decorative functions, artists have recently begun to interpret lichens as symbols of symbiosis and ecological continuity. The integration of lichen thalli into installations and mixed-media artworks represents a growing artistic dialogue between biology and environmental philosophy, emphasizing sustainability, coexistence, and resilience as core visual narratives (Ranković & Kosanić, 2019).



Figure 2. Some examples of the use of natural or colored lichens as accessories and decorative items in areas such as ornamental walls, terrariums, etc. (photos belong to the authors).

ECONOMIC USES OF LICHENS

Cosmetics

Lichens are among the preferred plant-based ingredients in perfume production due to their pleasant scents and long-lasting properties (Schneider, 1898). Playing a significant role in the cosmetics industry in the production of makeup, shampoos, and skincare products, lichens are also used in protective skincare creams due to their UV-protective properties (Müller, 2001; Elix & Stocker-Wörgötter, 1996). The most commonly used species in cosmetics include *Evernia mesomorpha*, *E. prunastri*, *Lobaria pulmonaria*, *Parmotrema chinense*, *P. kamtschadalis*, *P. perforatum*, *Pseudevernia furfuracea*, and *Roccella fuciformis* (Huneck, 1999).

Textile and Dye

The use of lichens has been known since ancient times due to their dyestuff properties. They are used as dye raw materials, especially in the food industry and in sectors such as food and cosmetics (Rather *et al.*, 2018; Shukla & Upreti, 2015). Lichen species belonging to the *Ochrolechia*, *Roccella*, *Gysophora*, and *Parmelia* genera are used in the chemical dye industry, especially in the production of Orsey dye and litmus paper, which is a pH indicator (Karamanoğlu, 1971; Sharma & Mohammad, 2020). Species such as *Cetraria islandica*, *Lobaria pulmonaria*, and *Alectoria sarmentosa*, as well as some lichens from the genera *Xanthoria*, *Parmelia*, *Bryoria*, and *Alectoria*, are frequently used in the textile industry. Lichens are also used in tanning processes in the leather industry (Elkhateeb *et al.*, 2022). *C. islandica*, *C. rangiferina*, and *L. pulmonaria* lichen species were actively used in industrial alcohol production (Schneider, 1898; Karamanoğlu, 1971). Today, studies on the use of dye-stuffs isolated from lichens continue.

Pesticides

The use of chemical pesticides, which have existed since the dawn of humanity and have been constantly evolving with the continuous increase in agricultural production, is also on the rise. In recent years, research has shown that lichens offer an alternative for obtaining natural insecticidal substances thanks to the compounds they contain (Kalra *et al.*, 2021). The toxic effects of lichen extracts on insects have been identified, and studies on their use as insecticides in agriculture have intensified (Emsen & Aslan, 2018). Lichens are increasingly regarded as promising sources of natural fungicidal agents with applications in agriculture and biotechnology. Characteristic secondary lichen metabolites, such as usnic acid, atranorin, and lecanoric acid exert inhibitory effects on several phytopathogenic fungi, including *Fusarium oxysporum* and *Aspergillus flavus*, and extracts from lichen species, particularly those from the genera *Pseudevernia*, *Evernia*, and *Parmelia*, have been shown to possess fungistatic or fungicidal properties against synthetic fungicides such as flucytosine and fluconazole (Furmanek *et al.*, 2022). These bioactive molecules may therefore provide sustainable, eco-compatible alternatives for fungal disease management, helping to limit resistance development and reduce chemical pesticide dependence in crop protection systems. Furthermore, the broad diversity of lichen-derived compounds, many of which are unique to lichens, enhances their potential as novel antifungal scaffolds (Stocker-Wörgötter, 2015). Initial reviews also emphasize that the majority of lichen metabolites remain under-investigated in the context of agricultural fungicides, suggesting rich future prospects for this line of research (Elkhateeb *et al.*, 2023).

Food for Humans

Lichens, which are edible and have been used as food by many cultures since ancient times, are rich in vitamins and minerals and have high nutritional value. They are still consumed as a healthy product in countries like Japan and China (Thakur *et al.*, 2023). Some lichens have long been used in cake and bread production, and many are consumed in the form of tea and spices. For example, in France, lichens are noted to be preferred in dietary products and pastry making (Dobson, 2000; Vinayaka & Kekuda, 2024). *Cetraria islandica* is the most widely consumed lichen species as food and has also been used in bread-making. Additionally, *Evernia prunastri*, *Lecanora esculenta*, and *Pseudevernia furfuracea* have been used in bread-making due to their flavor (Devkota *et al.*, 2017; Schneider, 1898). It is known that *Umbilicaria* species are known to be used in salads, *Cladonia rangiferina* with fruits, and *Parmelia perlata* as a spice (Karamanoğlu, 1971). *P. furfuracea* and *E. prunastri* are generally used in molasses production in Türkiye; *B. capillaris* is used in tea and alcohol production (Aoussar *et al.*, 2017; Öztürk *et al.*, 2013).

While some fungi and plants are poisonous, most lichens are non-toxic, have nutritional value, and are suitable for human consumption (Seaward, 2008). Usnic acid salt obtained from *Lobaria* species is frequently used in Finland and Switzerland (Rethinavelu *et al.*, 2023). Throughout history, several lichen species have been used as food, particularly in regions with limited vegetation. Among these, *C. islandica* (Iceland moss) has long been consumed in Northern Europe as porridge or tea due to its soothing and nourishing properties (Dobson, 2000). *C. rangiferina* (reindeer moss) served as an alternative carbohydrate source during famine periods in Scandinavia (Seaward, 2008).

In East Asia and China, *Umbilicaria esculenta* (rock tripe), considered an important culinary element, is still consumed in soups and salads due to its mineral richness and texture (Thakur *et al.*, 2023). *Lecanora esculenta* (*Aspicilia e.*), also called “manna lichen,” was traditionally used in the Middle East and Central Asia as a bread additive (Hawksworth, 2004). The aromatic lichen *Bryoria fremontii* is preferred as a spice in meat, fish, and chicken dishes; Native American peoples prepared it by roasting or boiling it with meat or fish. Indigenous peoples in North America prepared *Bryoria fremontii* by roasting or boiling it with meat or fish (Kuhnlein & Receveur, 1996; Thakur *et al.*, 2023). Aromatic species such as *E. prunastri* and *P.*

furfuracea were occasionally mixed into dough for flavor (Devkota *et al.*, 2017). Today, edible lichens attract renewed interest for their antioxidant compounds and nutritional potential, suggesting possible applications in functional foods (Rethinavelu *et al.*, 2023).

MEDICAL USES OF LICHENS

Pharmaceutical and Therapeutic Properties of Lichens

Lichens have been widely used for medicinal purposes throughout history by many civilizations, especially in Egypt and China (Shukla & Upreti, 2015). Most traditional medicines are known to originate from China. Since the 15th century, lichens have been documented as medicinal plants in many important works of medical history. In 5 different parts of Ibn-i Sina's work titled *El Qanun Fi't-Tıbb*, it is reported that lichens were used for medicinal purposes to prevent infection, relieve intoxication and fatigue, alleviate constipation (as ashnah oil), and treat inflammatory swellings (Çobanoğlu & Yavuz, 2003). It has been stated that lichens are widely used in folk medicine, either directly or added to other products, to treat skin problems, mouth sores, and respiratory and digestive system diseases (Rethinavelu *et al.*, 2023). Their ethnopharmacological uses and potential as a source of drug precursors have also been reported (Adenubi *et al.*, 2022).

In the current literature, the potential biological activities of lichen secondary metabolites such as antibacterial, antioxidant, antiviral, antifungal, antibiofilm, anti-inflammatory, antineurodegenerative, cytotoxic, antiproliferative, and anticancer are among the most studied subjects in recent years (Bhattacharyya *et al.*, 2016; Molnár & Farkas, 2010; Ranković & Kosanić, 2019). Lichens are used as raw materials in the modern pharmaceutical industry to obtain antibiotic products (Bhat *et al.*, 2023; Schneider, 1898; Thakur *et al.*, 2023). Research also reveals the natural sun-protective properties of lichen pigments (Korać & Khambholja, 2011; Solhaug *et al.*, 2003). Lichen compounds such as usnic acid and atranorin have been shown to inhibit cholinesterase enzymes, suggesting possible benefits in Alzheimer's disease management (Cocchietto *et al.*, 2002). Several lichen extracts also exhibit notable cytotoxic and antiproliferative actions against cancer cell lines, indicating a role in anticancer research (Solárová *et al.*, 2020). Moreover, depsides and depsidones demonstrate significant urease-inhibitory activity, which is important for controlling urease-producing pathogens (Shrestha & St. Clair, 2013). Certain species further display antidiabetic potential through mechanisms such as α -glucosidase inhibition and enhanced antioxidant activity (Ranković & Kosanić, 2015). Together, these findings identify lichens as promising natural sources of multifunctional therapeutic agents.

Biological Activity Potential of Lichens

It is estimated that approximately half of the world's lichens contain biologically active compounds and have significant potential as pharmaceutical raw materials. Numerous studies using different solvent extracts and isolated lichen compounds have been reviewed, and lichen species are summarized in [Table 1](#) according to their antibacterial, antioxidant, antiviral, antifungal, antibiofilm specific activities.

When evaluating the pharmaceutical raw material potential of lichens, it is evident that they produce natural compounds of high value for medical and biological applications as a result of unique biosynthesis processes shaped by their symbiotic structures. The chemical components specific to these organisms exhibit structural characteristics different from classical plant metabolites, diversifying their interaction with biological systems. In particular, lichen-derived secondary metabolites have been shown to have multifaceted effects on living organisms. Recent experimental findings reveal that some lichen extracts can exhibit strong activity against metabolic disorders. In this context, lichens are considered among natural resources with high potential that can provide alternatives or complementary qualities to existing pharmacological agents.

Table 1. Some of the bioactive lichen species and their target effects.

Activity	Lichen Species	Extract / Metabolite	Target / Effect	References
Antibacterial	<i>Ramalina farinacea</i>	Acetone extract	<i>Pseudomonas aeruginosa</i>	Çobanoğlu <i>et al.</i> , 2010
	<i>Ramalina farinacea</i>	Chloroform extract	<i>Escherichia coli</i>	Çobanoğlu <i>et al.</i> , 2010
	<i>Cladonia foliacea</i>	Usnic acid, Atranorin, Fumarprotocetraric acid	Gram (+) and Gram (-) bacteria	Garcia Rowe <i>et al.</i> , 1999; Francolini <i>et al.</i> , 2004; Ingolfssdottir, 2002; Yilmaz <i>et al.</i> , 2003
	<i>Parmelia saxatilis</i>	Acetone extract	Gram (+) and Gram (-) bacteria (not <i>E. coli</i>)	Kosanić <i>et al.</i> , 2014
Antioxidant	<i>Ramalina</i> spp.	Methanol, petroleum ether, acetone and water extracts	DPPH, FRAP, CUPRAC, BHA.	Sundararaj <i>et al.</i> , 2015; Stanly <i>et al.</i> , 2011; Luo <i>et al.</i> , 2010; Gulluce <i>et al.</i> , 2006
	<i>Parmelia</i> , <i>Platismatia</i> , <i>Ramalina</i> spp., <i>Umbilicaria</i> spp.	Ethanol and methanol extracts	DPPH, FRAP, ABTS, TPC.	Meysurova <i>et al.</i> , 2025; Gulluce <i>et al.</i> , 2006
	<i>Ramalina peruviana</i> , <i>Bulbothrix isidiza</i> , <i>Parmotrema tinctorum</i> , <i>Cladia aggregata</i>	Acetone and methanol extract	DPPH, TPC.	Stanly <i>et al.</i> , 2011
Antiviral	<i>Ramalina farinacea</i>	Methanol extract	Broad spectrum DNA and RNA viruses	Esimone <i>et al.</i> , 2009
	<i>Ramalina celastri</i> , <i>Teloschistes chrysophthalmus</i>	Usnic acid	Junin virus and Tacaribe virus	Fazio <i>et al.</i> , 2007
	<i>Cladia retipora</i> , <i>Pseudocyphellaria glabra</i> ,	Ethanol extracts	<i>Herpes simplex</i> virus type 1 and type 2, Poliovirus type 1.	Perry <i>et al.</i> , 1999
	<i>Pseudocyphellaria homoeophylla</i> , <i>Rocella montagnei</i>	Methanol extract	<i>Herpes simplex</i> virus type 1 and type 2	Bhat <i>et al.</i> , 2023

Activity	Lichen Species	Extract / Metabolite	Target / Effect	References
Antifungal	<i>Parmelia sulcata</i>	Acetone and methanol extracts	<i>Aspergillus flavus</i> , <i>A. fumigatus</i> , <i>Botrytis cinerea</i> , <i>Candida albicans</i> , <i>Fusarium oxysporum</i> , <i>Mucor mucedo</i> , <i>Paecilomyces variotii</i> , <i>Penicillium purpurescens</i> , <i>P. verrucosum</i> , <i>Saccharomyces cerevisiae</i> , <i>Trichoderma harsianum</i>	Ranković <i>et al.</i> , 2007
	<i>Pseudevernia furfuracea</i>	Acetone and methanol extracts	<i>Aspergillus flavus</i> , <i>A. fumigatus</i> , <i>C. albicans</i> , <i>P. purpurescens</i> , <i>P. verrucosum</i>	Kosanić <i>et al.</i> , 2014
Antibiofilm	<i>Evernia prunastri</i> <i>Usnea florida</i> <i>Cladonia squamosa</i> <i>Pseudevernia furfuracea</i> <i>Lasallia pustullata</i> <i>Pleurosticta acetabulum</i> <i>Parmelia saxatilis</i> <i>Xanthoparmelia conspersa</i> <i>Hypogymnia tubulosa</i>	Isolated metabolites such as Evernic acid, Squamatic acid, Stictic acid	<i>C. albicans</i>	Girardot <i>et al.</i> , 2021
	<i>Ramalina fastigiata</i> , <i>Evernia prunastri</i>	Acetone extract	<i>C. albicans</i>	Millot <i>et al.</i> , 2017

DPPH: stable radical diphenylpicrylhydrazyl, TPC: The total phenolic content, BHT: butylated hydroxytoluene, FRAP: Ferric reducing power, CUPRAC: Cupric reducing antioxidant capacity, ABTS: 2,2-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid.

Antibacterial activity

In addition to those in Table 1, many antimicrobial studies have been conducted on lichen metabolites. Among these, it has been determined that the metabolites of the genus *Ramalina* are highly effective on Gram (-) and Gram (+) bacteria. For example, Tian *et al.* (2025) determined that the acetone extract of *Ramalina farinacea* has an antibacterial effect against *Pseudomonas aeruginosa*. Similarly, the chloroform extract of *R. farinacea* has been recorded as active against *Escherichia coli* (Çobanoğlu *et al.*, 2010). Usnic acid, atranorin, and fumarprotocetraric acid, found in the chemical composition of *Cladonia foliacea*, have proven antibacterial properties (Yilmaz *et al.*, 2003). Many studies on lichen metabolites, especially usnic acid, have shown effectiveness against many bacteria (Garcia Rowe *et al.*, 1999; Ingolfssdottir, 2002; Francolini *et al.*, 2004). It has been reported that the acetone extract of *Parmelia saxatilis* lichen is effective against Gram (-) and Gram (+) bacteria, but not against *E. coli* bacteria (Kosanić *et al.*, 2014). Gulluce *et al.* (2006) found that the methanol extract of the lichen *P. saxatilis* had antibacterial properties against *E. coli*. In the same study, *R. pollinaria* methanol extract showed the strongest antibacterial activity, inhibiting 11 of the 35 bacterial species evaluated.

Antibiofilm activity

Biofilm-mediated infections pose a significant burden on global health due to the extraordinary capabilities of microorganisms embedded in biofilms, including resistance to antimicrobial treatments, evasion of the host immune system, and persistence on both biotic and abiotic surfaces. Biofilms are highly structured microbial consortia enclosed within an extracellular polymeric matrix that enables collective metabolic activity, enhanced stress tolerance, and a reduction in antibiotic susceptibility by up to several orders of magnitude compared with planktonic cells (Shrestha & St. Clair, 2013). Biofilm-associated pathogens contribute significantly to chronic wound infections, catheter- and implant-related complications, and biofouling in industrial systems. This highlights the need for innovative antibiofilm agents that can disrupt these resilient microbial communities. Lichens have recently attracted increasing scientific interest as a potential source of such agents.

Lichens synthesize a highly diverse range of secondary metabolites, primarily depsids, depsidons, dibenzofurans, and pulvinic acid derivatives, which are not commonly found in higher plants or free forms of symbiont organisms (Cortes *et al.*, 2020). Recent data have provided strong evidence that these compounds, possessing various biological activities, can also interfere with key stages of biofilm development. For example, three major lichen metabolites, usnic acid, atranorin, and fumarprotocetraric acid, have been shown to significantly inhibit *Staphylococcus aureus* biofilm formation and reduce biomass in methicillin-resistant strains (Pompilio *et al.*, 2013). These findings underscore the potential of lichen-derived compounds to target Gram-positive pathogens that are notoriously difficult to eradicate. Similarly, evernic acid has been reported to interfere with multiple stages of *Candida albicans* biofilm development, including adhesion, hyphal transition, and the stability of mature biofilms, demonstrating potent antibiofilm activity against clinically relevant fungal pathogens (Girardot *et al.*, 2021). Broad-spectrum screenings have further indicated that crude lichen extracts often display greater antibiofilm efficacy than isolated metabolites, possibly due to synergistic interactions between phenolic constituents (Ranković & Kosanić, 2012). Recent ecological investigations have revealed that lichen-associated bacteria and fungi produce bioactive molecules that can modulate microbial interactions and may enhance the overall antibiofilm potential of the lichen thallus (Cortes *et al.*, 2020). Despite this emerging evidence, the antibiofilm capacities of many lichen taxa remain insufficiently explored, particularly in relation to solvent-dependent variability in the extraction of phenolic compounds.

Antioxidant activity

As shown in Table 1, many studies have reported that species belonging to the genera *Cetraria*, *Ramalina*, *Parmelia*, *Platismatia*, *Ramalina*, and *Umbilicaria* possess high antioxidant capacity (Grujić et al., 2014; Gulluce et al., 2006; Luo et al., 2010; Sundararaj et al., 2015; Meysurova et al., 2025). A study conducted in Malaysia determined that selected lichens (*Ramalina peruviana*, *Bulbothrix isidiza*, *Parmotrema tinctorum*, and *Cladia aggregata*) had significant levels of total phenolic content and antioxidant activity (Stanly et al., 2011).

Antiviral activity

Lichens are also notable for their antiviral properties. Experiments with different extracts of *Ramalina farinacea* have revealed that this lichen has a broad spectrum of activity against DNA and RNA viruses (Esimone et al., 2009). Usnic acid, obtained from the mycobiont of *R. celastri*, has been reported to have an antiviral effect against Junin virus (JUNV) and Tacaribe virus (TCRV) belonging to the Arenaviridae family found in humans (Fazio et al., 2007). In the same study, parietin, obtained from the mycobiont *Teloschistes chrysophthalmus*, was also found to be effective against the same viruses. A study conducted in New Zealand (Perry et al., 1999) showed that the lichen metabolites of *Cladia retipora*, *Pseudocyphellaria glabra*, and *P. homoeophylla* species have antiviral effects against *Herpes simplex* virus (HSV), which belongs to the Alphaherpesviridae family and is commonly known as the cold sore virus, and Poliovirus, which causes poliomyelitis, while another study (Bhat et al., 2023) showed that *Roccella montagnei* has antiviral effects against HSV-1 (type 1) and HSV-2 (type 2).

Antifungal activity

The antifungal effect of acetone and methanol extracts of *Parmelia sulcata* has been reported against *Aspergillus flavus*, *Aspergillus fumigatus*, *Botrytis cinerea*, *Candida albicans*, *Fusarium oxysporum*, *Mucor mucedo*, *Paecilomyces variotii*, *Penicillium purpureescens*, *P. verrucosum*, *Saccharomyces cerevisiae*, and *Trichoderma harsianum* (Ranković et al., 2007). In another study, acetone and methanol extracts of lichen *Pseudevernia furfuracea* were found to be antifungally active against *A. flavus*, *B. cinerea*, *C. albicans*, *M. mucedo*, and *P. verrucosum*. Gulluce et al. (2006) evaluated methanol extracts of *Parmelia saxatilis*, *Platismatia glauca*, *Ramalina pollinaria*, *R. polymorpha*, and *Umbilicaria nylanderiana* individually against a comprehensive panel of 54 microbial cultures containing 35 bacteria as well as 18 fungal and yeast species. All five species demonstrated antifungal activity against a variety of fungi, including *C. albicans*, *Aspergillus* spp., and *Fusarium* spp. Furthermore, three of the lichen species exhibited notable anticandidal activity, whereas *P. saxatilis* and *P. glauca* showed no activity against *C. albicans* (Gulluce et al., 2006).

Uses and Bioactive Functions of 15 Prominent Lichen Species

The compilation of literature data revealed that lichens are primarily utilized in five major sectors: medicine and pharmacy, cosmetics, textile and dye production, food industry, and agriculture. The usage areas of the 15 most common species (*Bryoria fremontii*, *Cetraria islandica*, *Cladonia rangiferina*, *Hypogymnia physodes*, *Letharia vulpine*, *Parmelia sulcata*, *Peltigera canina*, *Pseudevernia furfuracea*, *Ramalina farinacea*, *Roccella tinctoria*, *Stereocaulon* spp., *Umbilicaria esculenta*, *Usnea florida*, *Xanthoria parietina*) selected from studies on the use and bioactivity of lichens are shown in Table 2.

Table 2. Prominent lichen species and their reported applications worldwide.

Lichen Species	Primary Use Area	Reported Bioactive/ Functional Role	Geographic/ Cultural Origin	References
<i>Bryoria fremontii</i>	Food (Native American tribes)	Carbohydrate-rich nutritional source	North America	Skujins, 1970; Turner, 2014
<i>Cetraria islandica</i>	Food (bread, tea), leather tanning, dye	Demulcent, astringent, dye precursor, Antioxidant, Antimicrobial, Anticancer	Iceland, Central Europe	Karamanoğlu, 1971; Elkhateeb <i>et al.</i> , 2022; Grujić <i>et al.</i> , 2014
<i>Cladonia rangiferina</i>	Animal feed, food, alcohol industry	Nutritional and antioxidant	Northern Europe, Scandinavia	Seaward, 2008; Schneider, 1898
<i>Evernia prunastri</i>	Perfumery, decorative arts, pharmaceuticals	Fragrance fixative, antimicrobial	France, Nepal, Morocco	Huneck, 1999; Devkota <i>et al.</i> , 2017; Aoussar <i>et al.</i> , 2017
<i>Hypogymnia physodes</i>	Air quality biomonitoring, folk medicine	Antioxidant, antimicrobial	Northern and Central Europe	Zeković <i>et al.</i> , 2016; Nash, 2008
<i>Letharia vulpina</i>	Poison (historical), ritual use	Vulpinic acid (toxic pigment), dye	Scandinavia, Siberia	Brodo <i>et al.</i> , 2001; Schultes, 1937
<i>Parmelia sulcata</i>	Traditional remedies, textile dye	Antibacterial, antifungal (atranorin-rich)	Europe, Balkans, North America	Ranković <i>et al.</i> , 2011; Ingólfssdóttir, 2002
<i>Peltigera canina</i>	Wound healing (folk use), veterinary remedies	Antibacterial, anti-inflammatory	Europe, Asia	Mitrović <i>et al.</i> , 2011; Huneck, 1999
<i>Pseudevernia furfuracea</i>	Mummification, perfumery, bread production	Antioxidant, antimicrobial	Egypt, Europe, Turkey	Abdel-Maksoud & El-Amin, 2011; Broad, 1989; Devkota <i>et al.</i> , 2017
<i>Roccella tinctoria</i>	Purple dye (orchil), textile industry	Dye precursor (orcein, orchil)	Mediterranean, Canary Islands	Cooksey, 2013; Cardon, 2007
<i>Stereocaulon</i> spp.	Traditional medicine, dyeing	Antioxidant, cytotoxic, dye	Tibet, Nepal, Arctic regions	Devkota <i>et al.</i> , 2017; Huneck & Yoshimura, 1996
<i>Umbilicaria esculenta</i>	Food delicacy (“Iwatake”), traditional medicine	Antioxidant, immunomodulatory	Japan, China, Korea	Miura, 1976; Yoshimura, 1994
<i>Usnea florida</i>	Medicinal and antimicrobial	Usnic acid (antibacterial, antioxidant)	Turkey, Europe	Çobanoğlu <i>et al.</i> , 2010; Ranković <i>et al.</i> , 2014
<i>Xanthoria parietina</i>	Traditional dyeing, folk medicine	Parietin (antimicrobial, antioxidant), dye pigment	Europe, Turkey, Middle East	Solhaug & Gauslaa, 2004; Türk <i>et al.</i> , 2017

Table 2 shows that many studies have documented the diverse uses and bioactivity characteristics of commonly used lichen species from different geographical regions of the world, across various sectors such as food, animal feed, textiles, perfumery, and medicine.

DISCUSSION and CONCLUSION

Lichens, as extraordinary symbiotic mysterious organisms that combine ecological importance with pharmacological and industrial potential, have been frequently used by societies for various purposes since ancient times. From the past to the present, the use of lichens as important natural biological resources has become widespread in sectors such as medicine, pharmacy, cosmetics, chemistry, dyes, food, and agriculture, especially in the medical, textile, and cosmetic industries. The recently discovered biological effects of lichen secondary metabolites, such as antifungal, antibacterial, antioxidant, antitumor, anticarcinogenic, and antiviral, have made lichens even more valuable.

The findings summarized in this review reveal that lichens, with their composite life forms, have accompanied humanity from ancient civilizations to the present day. In modern times, they have gained growing attention as sustainable natural resources in the fields of pharmacy, cosmetics, biotechnology, and environmental sciences. Their diverse secondary metabolites display notable antioxidant, antimicrobial, antifungal, antiviral, and anticancer properties, positioning lichens as promising sources for developing new bioactive molecules. Nevertheless, challenges remain in ensuring sustainable harvesting, improving cultivation techniques, and standardizing extract composition. To advance lichen-based research, future investigations should emphasize eco-friendly cultivation systems, metabolomic and genomic analyses, and interdisciplinary collaborations connecting ethnobotany with molecular biotechnology. Such approaches will enable a clearer understanding of biosynthetic mechanisms and facilitate the safe and efficient industrial utilization of lichen-derived compounds.

Ultimately, lichens can be regarded not only as sensitive components of natural ecosystems but also as reservoirs of untapped chemical and biological potential. Their integration into modern science and technology may contribute significantly to innovation in medicine, agriculture, and green industries, while supporting long-term environmental sustainability.

Limitations and Translation Difficulties

- ❖ Although lichens are increasingly recognized as a source of pharmacologically important molecules, their transition from experimental research to medical application is hampered by several key challenges.
- ❖ One of the most significant challenges is the nature of lichen metabolite production; this production varies depending on ecological niche, developmental stage, and symbiotic interactions, leading to variable biological responses.
- ❖ The limited growth capacity and ecological sensitivity of lichens restrict the possibility of obtaining sufficient material for comprehensive pharmacological development. All these factors combined make it difficult for lichen-based biological activity studies to find their place among clinically applicable products.

Future research should focus on further developing;

- ❖ Biotechnological cultivation and in vitro production of lichen metabolites to ensure sustainability.
- ❖ Multiomics approaches (genomics, metabolomics) to uncover biosynthetic pathways and optimize metabolite yield.
- ❖ Cross-sectoral integration linking ethnobotanical knowledge with modern pharmacology to identify novel drug leads.

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The authors declare no conflict of interest. This review complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Authorship Contribution Statement

H.K.S.: Investigation, Resources, Visualization, Software, Formal Analysis, and Writing-original draft.
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