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An Overview on Lichen's Morphology, Chemistry of Derived Products, and Current Scenario

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Abstract
Lichens, the mutual symbionts of a fungus with microalga and/or a cyanobacterium, are important constituents of many ecosystems. A large number of natural products and secondary metabolites have been obtained from lichens, especially, dyes, drugs, and other constituents. In the present scenario, these natural products/ secondary metabolites have shown impressive range of biological activities such as antimicrobial, anticancer, antifungal, antioxidant, antiviral, anti-inflammatory, analgesic, antipyretic activities, and many more. Traditionally, lichens as whole and their extracts were used to treat various diseases and ailments around the world. This chapter deals with the discussion on lichen's morphology and chemistry of derived products.

Keywords: Lichen, morphology, biological activity, antibacterial, antifungal, dyes

1.1 Introduction

Lichens are an inevitable segment of all ecosystems due to their symbiotic nature not only fixation of essential nutrients from the air to the soil but also production of fresh oxygen into air. Lichens are slowest growing, unique in nature and shape, stable, and self-supporting symbiotic organisms propagate on living organisms such as shrubs, tortoise's carapaces, trunks and woods of trees, etc., and mounted surfaces like soil, bricks,

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and many more, in an association of a fungi with algal isolate [1, 2]. It is estimated that lichens are survived with approximately 25,000 species in which 98% are Ascomycotes fungal partners and remaining 2% are cyanobacteria partners [3]. Old documentations reveal the uses of lichens and their extracts/obtained products have been utilized, as one of the best traditional medicines for the treatment of several human (wounds, burns, fissures, impotency, etc.), plants (rots and worts), and animal diseases (disfertility, wounds, skin issues) [4, 5]. Lichen found to exhibit manifold biological activities in various screenings, for example, antimicrobial, anticancer, antifungal, antioxidant, antiviral, anti-inflammatory, analgesic, antipyretic, growth inhibitory, and enzyme inhibitory activities, etc. [1–8]. Extracts of many lichen species of the genus *Usnea* were found usable as analgesic remedy in several countries of Asia, Europe, Africa, and Argentina [9].

The plant-like portion of the lichens is morphologically multifarious and generally often called as thallus. Primarily, the main three categories of lichens were recognized already such as crustose, foliose, and fruticose [1]. Furthermore, lichenologists, chiefly Baron, Dobson, Smith, and their co-workers described comprehensive diversities of thallus types (Table 1.1). Lichens inherently synthesize various types of secondary metabolites. There are more than 1,000 lichen-derived substances/biomolecules that have been identified through analytical and experimental methods [2]. The discussion on lichen's thallus morphology and the chemistry of their derived products with their considerable applications is highlighted herein this chapter.

1.2 The Lichen's Body: Thallus Morphology

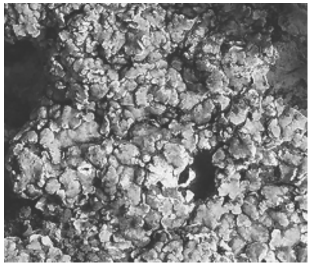
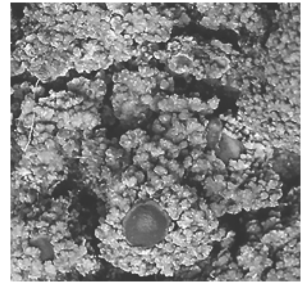
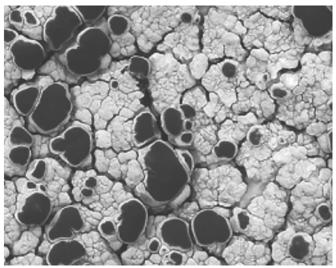
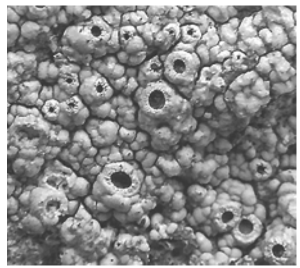
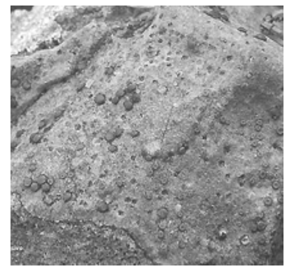
Lichens are found growing on high peaks from the sea to the mountains such as wood, trunks, barks of trees, crustacean to the soil, rocks, walls, and many more places either in the sunlight or in the dark grooves. Abundantly, they propagate in clean environment like, forest ecosystem, and in a wide range of locations and climates from the Polar Regions to the tropics. Thus, they act as environmental indicator. Lichen thallus is the vegetative part and morphologically diversified in nature with branched, proliferated, tabulate, leafy, fibrous, tiny plates, layers of powdery granules, or without any specified thallus [10]. The main three categories of lichens were recognized already such as crustose, foliose, and fruticose [9]. Furthermore, lichenologists, chiefly Baron, Dobson, Smith, and their co-workers described comprehensive diversities of thallus types (Table 1.1) [5–10].

Table 1.1 Morphological diversities in lichen thalli.

Lichen types	**Thallus morphology**		
Foliose			
	Evernia prunastri	*Peltigera membranacea*	*Parmotrema perlatum*
Fruticose			
	Usnea subfloridana	*Roccella phycopsis*	*Ramalina polymorpha*

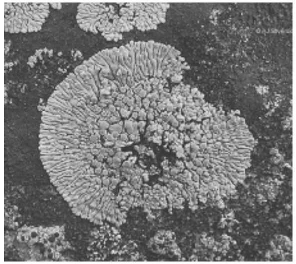
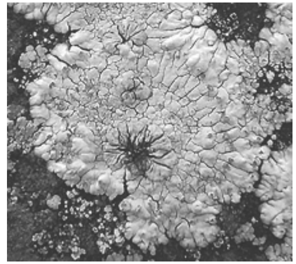
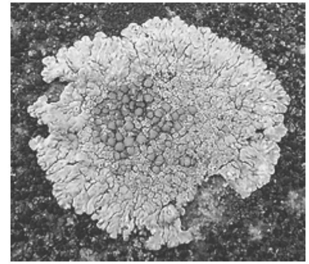
(*Continued*)

Table 1.1 Morphological diversities in lichen thalli. (*Continued*)

Lichen types	**Thallus morphology**		
Squamulose			
	Squamarina cartilaginea	*Cladonia subcervicornis*	*Vahliella leucophaea*
Crustose			
	Ophioparma ventosa	*Diploschistes scruposus*	*Caloplaca ochracea*

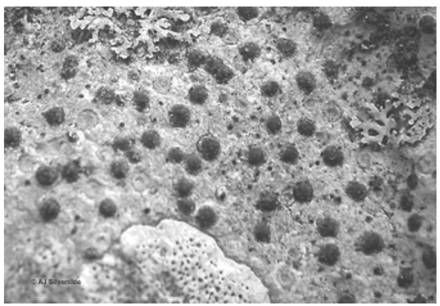
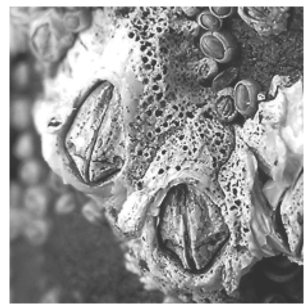
(*Continued*)

Table 1.1 Morphological diversities in lichen thalli. (*Continued*)

Lichen types	**Thallus morphology**		
Placodioid lichens			
	Caloplaca thallincola	*Placopsis lambii*	*Lecanora muralis*
Leprose			
	Lepraria incana	*Caloplaca chrysodeta*	*Chrysothrix candelaris*

(*Continued*)

Table 1.1 Morphological diversities in lichen thalli. (*Continued*)

Lichen types	**Thallus morphology**		
Filamentous			
	Cystocoleus ebeneus	*Ephebe lanata*	*Polychidium muscicola*
Without any definite shape or lichens without any visible thallus			
	Acrocordia conoidea	*Collemopsidium foveolatum*	

1.2.1 Foliose

Foliose lichens mostly grow up in stratum with variable upper and lower surfaces. The thallus are somewhat flat but are convoluted or in leafy form and also can stand in erect mode away from the substrate like a swarm with multiple branches. Examples are *Evernia prunastri*, *Pseudevernia furfuracea*, *Evernia prunastri*, *Peltigera membranacea*, and *Parmotrema perlatum*.

1.2.2 Fruiticose

Fruiticose lichens are tickering in air like pendulum and have either a flat or a branched thallus covered by a solo outer cortex. For example, flattened branches—*Ramalina sp.*, and with branched aerial lobes such as *Evernia sp*. Other examples are *Usnea subfloridana* and *Roccella phycopsis.*

1.2.3 Squamulose Lichens

The squamulose lichens are specific arrangements of squamules (overlapping scales) which are heavy in weight, oblate, and succinct in size. Anatomically, squamulose lichens indicate variation to the smaller foliose lichens in which the presence of lower cortex is either not and or is highly differentiated. In case of *Catapyrenium* and *Placidium* species, medulla part may be sometimes colored. More examples are *Squamarina cartilaginea*, *Cladonia subcervicornis*, and *Vahliella leucophaea*.

1.2.4 Crustose

Crustose lichens mostly grow and spread over the crust such as soil, bark, and trunks of trees, and rocks with much variation like yellow, red, and grey-green in color-appearance, but found abundantly in grey-green color. Such lichens are firmly attached to the surface and are sighted in a bag-like texture. Examples are *Ophioparma ventosa*, *Diploschistes scruposus*, and *Caloplaca ochracea.*

1.2.5 Placodioid/Crustose-Placodioid/Squamulose-Placodioid

This is a true variant of crustose and squamulose that alternatively became placodioid. Some placodioid species are *Caloplaca thallincola*, *Placopsis lambii*, and *Lecanora muralis*. This type of thallus does not attach too much with the base and have a lower cortex. Also, the lobe margin extends into narrow and spread after.

1.2.6 Leprose

The surface of this type of thallus made up of lumps or granules like structure in which algal and fungal hyphae are present. Examples are *Lepraria incana*, *Caloplaca chrysodeta*, and *Chrysothrix candelaris.*

1.2.7 Filamentous Lichens

Filamentous lichens are also known as fibrous lichens owe to its shape. The morphology of the lichen generally seems dark green in appearance. At inner side algal cells like fiber are situated and the fungal hypae around the fiber form an outer sheath, for example, *Trentepohlia* or trichome-forming cyanobacteria. *Ephebe lanata* is a type of cyanolichens, which is blackish green in color and seen as smooth shrub or bear. Other common examples given are *Cystocoleus ebeneus* and *Polychidium muscicola*.

1.2.8 Without any Definite Shape or Lichens Without any Visible Thallus

Rarely, in this type of Lichens, no thallus are definitely visible. It can be understood in two ways, either it disappears very quickly or it gets immersed in the substrate in which both algae cells and fungal hyphae are present together. Examples of this group are *Acrocordia conoidea* and *Collemopsidium foveolatum*.

1.3 Chemistry of Lichen-Derived Products

Asahina [11], a Japanese scientist, explored diversified chemistry of lichens, with respect, concerning the initial work of two great botanists and entomologists of 18th centuary, William Nylander from Finland and Friedrich Wilhelm Zopf from Germany [12]. In the mid of 19th century, biogenic origin and phylogenetic significance of lichens have accumulated steadily worldwide, and lichen-derived biomolecules have attracted much attention. Consequently, Shibata, another Japanese researcher, performed exhausted work on the biosynthesis process for lichen-derived metabolites. Toward step ahead, they also introduced the process of microcrystallization with respect to the chemistry of lichen-derived compounds [13]. According to Molnar *et al.* (2010), about 1,050 lichen-derived substances have been identified out of which more than 700 were characterized by their chemical structure, mostly bears ester group [2, 14]. Biosynthetically, lichen metabolites can be categorized into four types (Figure 1.1) [15].

(i) Polyketide pathway shows the formation of the maximum lichen-derived compounds such as fatty acids and related compounds, phenolic compounds, etc.,
(ii) Shikimic acid pathway generally responsible for the generation of pulvinic acid derivatives and terphenylquinones,
(iii) Mevalonic acid pathway produces chiefly steroids and terpenes, and
(iv) Photosynnthesis generates sugars.

Lichen metabolites may be categorized into the following classes according to chemical structures (Figure 1.2):

(i) Aliphatics (acids, zeorin like compounds, polyols),
(ii) Carbohydrates (mono, di, and polysaccharides), and
(iii) Aromatics (almost constituents).

Aliphatic metabolites found are acids, polyols, and zeorin like compounds, whereas carbohydrates are the types of mono and complex saccharides. Based on the studies [4–7], the major class aromatics is widely distributed involving, phenolic compounds (orcinol and derivatives), lactones (protolichesterinic acid, nephrosterinic acid), quinines (parietin),

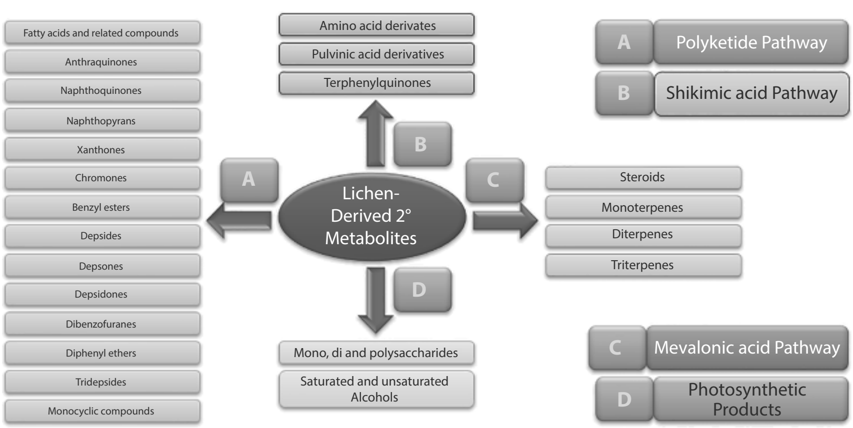


Figure 1.1 Different biosynthetic pathways of Lichen's secondary metabolites/substances.

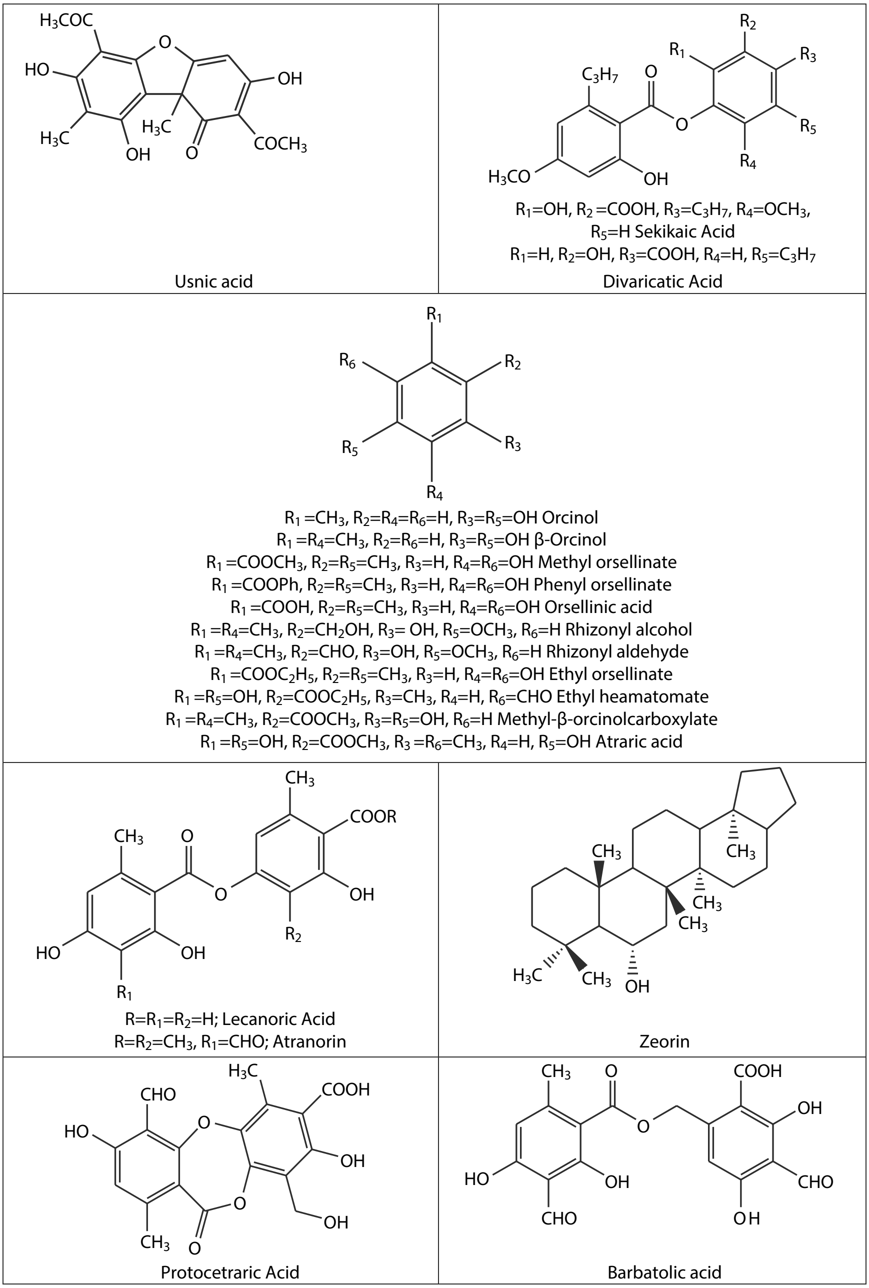


Figure 1.2 Chemical structures of some lichen-derived metabolites. (*Continued*)

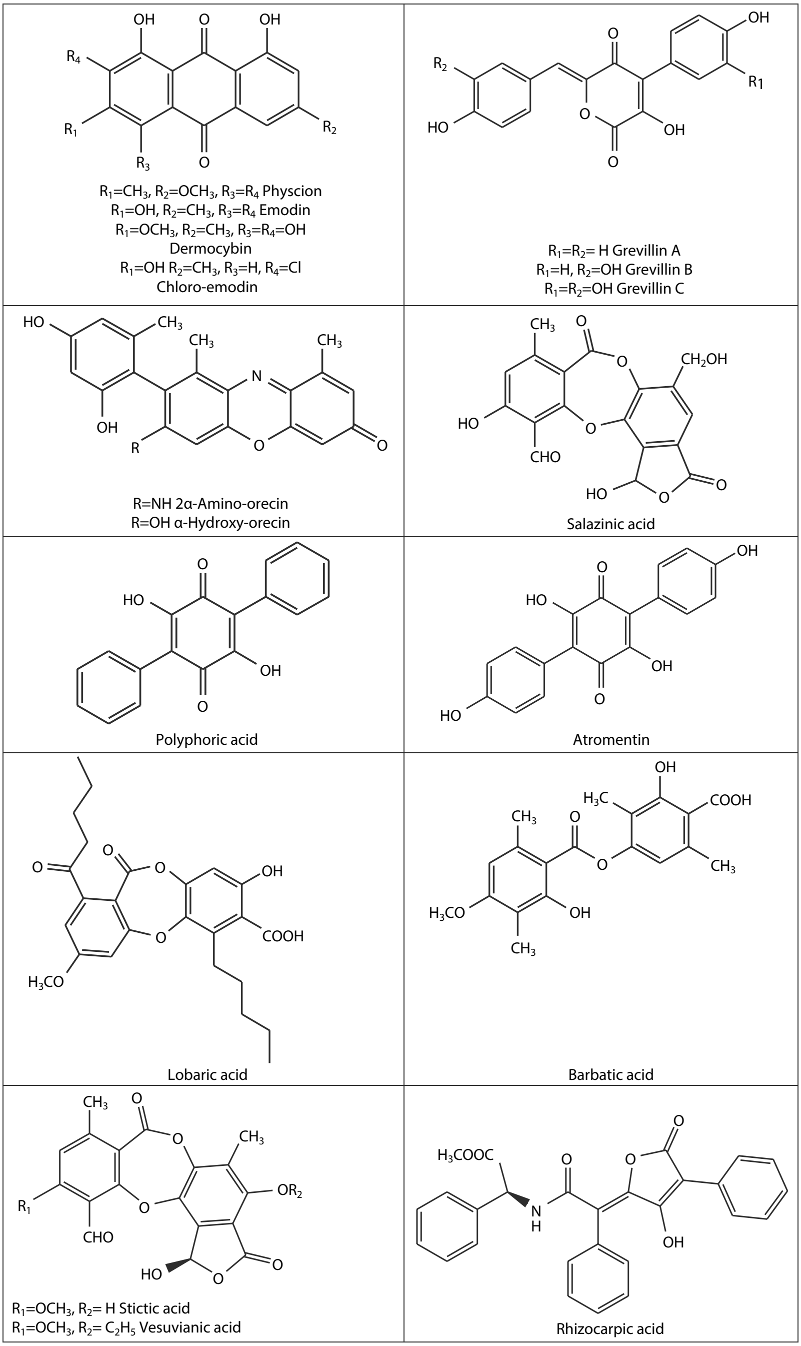


Figure 1.2 (*Continued*) Chemical structures of some lichen-derived metabolites.

dibenzofurans (pannaric acid, usnic acid), depsides (homosekikaic acid, barbatic acid), depsones (picrolichenic acid), depsidones (salazinic acid), xanthones (lichexanthone), pulvinic acid derivatives (pulvinic acid), quinones (physcion, emodin), etc. (Figure 1.2).

Moreover, phytochemicals in large number were characterized in separate lichen species. A cyclic depsipeptide, arthogalin was reported from an endemic species of lichen of Galapagos Islands [16]. *Xanthoparmelia scabrosa*, native to central Asia, was analyzed for possible new chemical compounds along with previously reported compounds. New compounds (Figure 1.3) were phenylalanine-derived scabrosin esters [17],

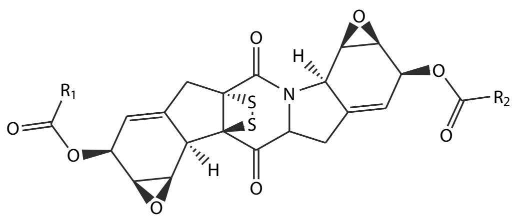
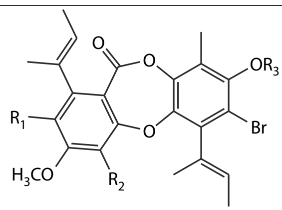
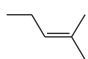
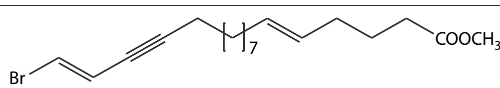
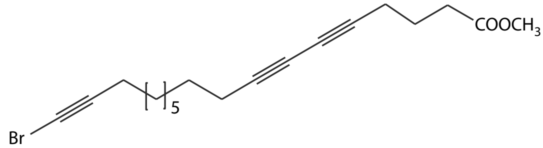
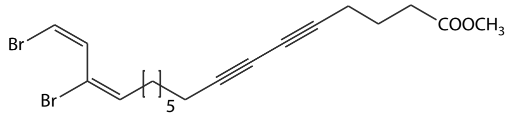
Scabrocin esters	
	$R_1 = R_2 = CH_3$ Dimethyl scabrocin ester $R_1 = R_2 = CH_3H_7$ Dipropyl scabrocin ester $R_1 = CH_3$, $R_2 = CH_3H_7$ Methylpropyl scabrocin ester $R_1 = CH_3$, $R_2 = C_5H_{11}$ Methylpentyl scabrocin ester $R_1 = CH_3H_7$, $R_2 = C_5H_{11}$ Propylpentyl scabrocin ester $R_1 = R_2 = C_5H_{11}$ Dipentyl scabrocin ester
Brominated depsidones	
	$R_1 = H$, $R_2 = CH_3$, $R_3 = H$ Acarogobein A $R_1 = Br$, $R_2 = CHO$, $R_3 =$  Acarogobein B
Brominated acetylenic fatty acids	 18-Bromo-(5E,17E)-octadeca-5,17-diene-15-yonoic acid methyl ester

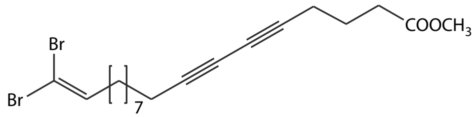
Figure 1.3 Chemical structures of phenylalanine-derived scabrosin esters, brominated depsidones, brominated acetylenic fatty acids, monotetrahydrofuranic acetogenins and mono and di-prenylated xanthosides. (*Continued*)



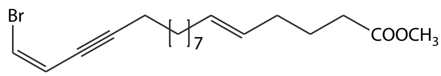
8-Bromo-octadeca-5,7,17-triyonoic acid methyl ester



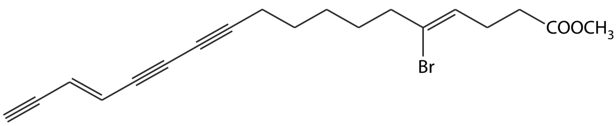
16,18-Dibromo-(5E,17E)-octadeca-5,17-diene-5,7-diyonoic acid methyl ester



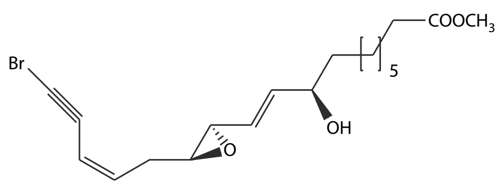
18,18-Dibromo-17-octadecene-5,7-diyonoic acid methyl ester



18-Bromo-(5E,17Z)-octadeca-5,7-diene-15-yonoic acid methyl ester



18-Bromo-(5E,15Z)-octadeca-5,5-diene-11,13,17-triyonoic acid methyl ester



18-Bromo-9-hydroxy-12,13-*trans*-epoxy-(10E,15Z)-octadeca-10,15-diene-17-yonoic acid methyl ester

Figure 1.3 (*Continued*) Chemical structures of phenylalanine-derived scabrosin esters, brominated depsidones, brominated acetylenic fatty acids, monotetrahydrofuranic acetogenins and mono and di-prenylated xanthosides.

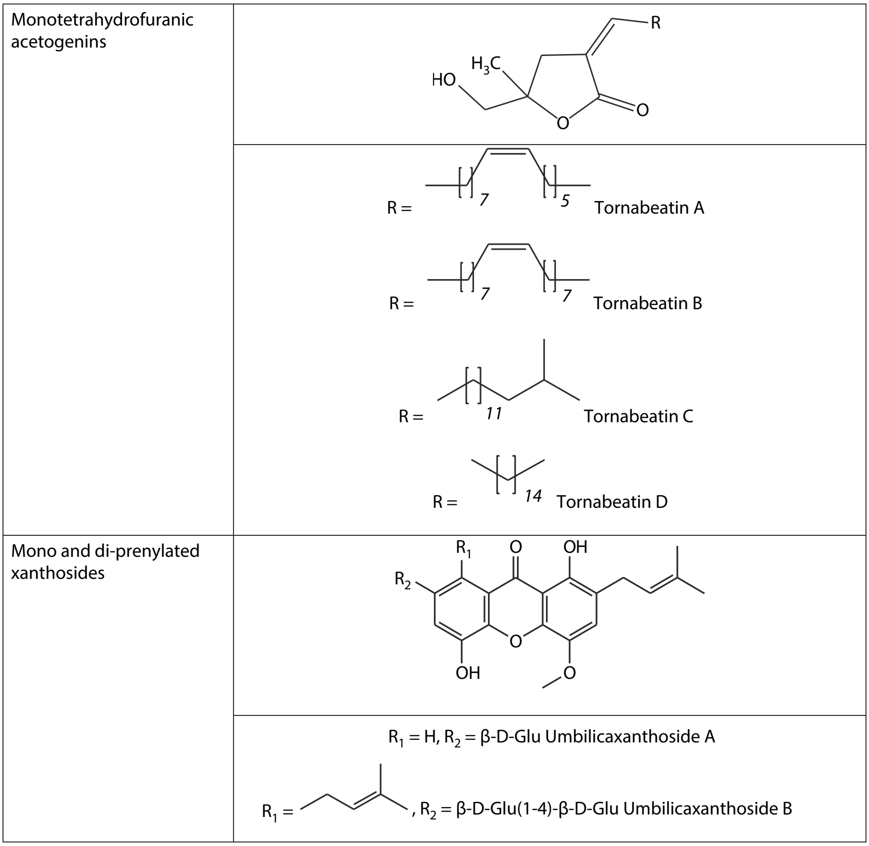
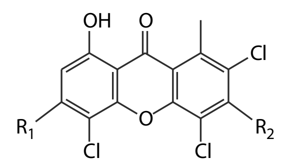


Figure 1.3 (*Continued*) Chemical structures of phenylalanine-derived scabrosin esters, brominated depsidones, brominated acetylenic fatty acids, monotetrahydrofuranic acetogenins and mono and di-prenylated xanthosides.

brominated depsidones [18], and brominated acetylenic fatty acids [9]. Rezanka and collaborators [19–22] identified γ-lactones with long-chain fatty acids, macrolactone glycoside, and monotetrahydrofuranic acetogenins (Figure 1.3) in some commonly grown lichen species of Central Asia. Xanthosides (mono- and di-prenylated xanthone glucosides) (Figure 1.3) that are isolated from the lichen, *Umbilicaria proboscidea*, by Torres *et al.* (2004), are found in Schrader of the Ural Series of mountains [23].

Besides many halogenated xanthone classes have been identified such as usneaxanthones A, Arthothelins are obtained several genus of *Lecanora* such as *L. broccha*, *L. straminea*, *L. flavopallescens*, *L. ingae*, *L. bolanderi*, *L. sulphurata L. andrewii*, *L. flavidopallens*, *L. pruinos and L. pinguis*, and the genus *Lecidella*, for example, *L. quema*, *L. asema*, *L. vorax*, *L. meiococca*, and *L. subalpicida.* The compounds of similar class also isolated from *Buellia sp.*, *Melanaria melanospora*, *Arthothelium pacificum*, and *Dimelaena australiensis.* Other class of Asemones was identified in *Micarea isabellina*, *M. austroternaria*, *Lecanora broccha*, *Buellia sp.*, *Lecidella asema*, *L. subalpicida*, and *Pertusaria pycnothelia* (Figure 1.4) [24–27]. Furthermore, Ratnayake and coworkers reported some heterocyclic polyketides from *Kibdelosporangium* sp. with class Isokibdelones (Figure 1.5) [28].

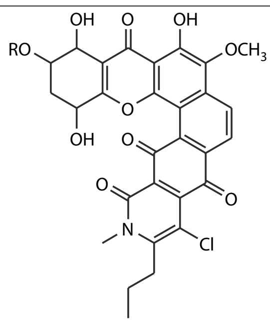


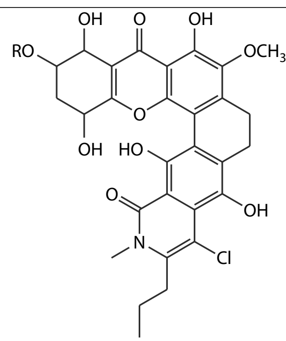
R_1 = OH, R_2 = OH Asemone

R_1 = OCH_3, R_2 = OH 3-*O*-methylasemone

R_1 = OH, R_2 = OCH_3 6-*O*-methylasemone

Figure 1.4 Chemical structure of Asemones.





R = H Isokibdelone A R = *Rhambose* Isokibdelone A rhamnoside	Isokibdelone C

Figure 1.5 Chemical structure of Isokibdelones.

1.4 Current Scenario of Lichens and Derived Products Thereof

From ancient times, several species of lichens have been used for diverse purposes. Chiefly, the aqueous extract of purple pigments obtained from *Roccella species* was applied to colorable articles and clothings to make them colorful. This extract is used as pH indicator. Also, brown pigments from *Evernia*, *Ochrolechia*, and *Parmelia* genus were called *crottal* by Romans [29]. Lichens have found able to possess environmental biodetection property. This ability attributed to their sensible behavior toward many air pollutants, for example, oxides of sulfur and nitrogen and specific heavy metal ions [30].

Lichens are one of the important flora of the Asia continent having a vast topographical and climatic diversity and a large varieties have been identified in India [31]. In the Indian Ayurvedic system of medicine, lichens have been found effective in the treatment of many diseases like asthma, leprosy, wound-healing, and bronchitis. Also, the medication/recipe based on lichens was observed emphatic to cure heart as well as spleen size problems. In addition, lichens are consecutively used in the Unani system of medicines to treat a number of curable and incurable ailments, especially, heart problems and stomach-related disorders—inflammation of liver and spleen, diarrhea, and vomiting. Some species are also used as blood purifier and as a cosmetic ingredient [32].

Lichens have been used and recognized for centuries as folk medicines by native peoples of Indians, Chinese, Americans, Europeans, and Haitian in the curing of various ailments.

However, the recurrence of advanced pathogens is challenging and global concern from drug-resistant microbial infections. Microbial resistance therapies are urgently require efforts in industry and scientific research communities and the need has opened new vistas in the discovery of new antimicrobial alternatives based on natural origination that can be derived from plants, animals, microorganisms, algae, or mushrooms [33]. Many natural products have been used as antimicrobial agents. For example, antimicrobial peptides (AMPs) are the auto-defensive proteins reported in plants, animals/insects, and other living systems [34]. With respect to lichens, several studies were performed on the bioactive profile and found to be satisfactory results. The lichenologists express much attention on the lichens and their derived secondary metabolites on account of the inherited valuable bioactive properties. In this regard, about 50% certain species of the known lichens have shown excellent antimicrobial potential [35]. Some species are capable of possessing similar functionality as of vaccines. For instance, *Parmelia sulcata* and *Peltigera apthosa* are found very effective to treat rabies and thrush disease serially [36]. Recent researches demonstrated that many lichen species are found to have antimicrobial, antiprotozoal, anticancer, antiviral, antioxidant, antipyretic, anti-inflammatory, and antidiabetic properties [3–10, 33–36].

Minimum Inhibitory Concentrations (MIC) values for MeCOMe and MeOH extracts about 34 species of Lichens were investigated in detail against four isolates of pathogenic bacteria by Shrestha *et al.* (2014), reproduced in Table 1.2. In this study, most of the tested extracts most of the selected lichen extracts showed good antibacterial potential on the tested pathogenic isolates, *viz.*, *S. aureus* (0), *S. aureus* (COL), and *P. aeruginosa*, but showed no significant activity against *E. coli* strains. The antibacterial potential in considerable manner toward *E. coli* strain was observed for the extracts of *Letharia* species (*L. vulpine* and *L. columbiana*) as well as *Vulpicida canadensis.* In overall, MeCOMe extracts showed superior activity than MeOH extracts [37]. Furthermore, lichen-derived isolated compounds have been tested against several pathogenic organisms. In contrast, two carboxylic acids, namely, isousnic acid and protolichesterinic acid, derived from various lichen species saliently possessed bio-functionality for *Chlorella vulgaris* and *C. sorokiniana*. In addition, few compounds (usnic acid and evernyl) showed no effectiveness against *C. sorokiniana* and *Scenedesmus subspicatus*, but hold activeness for *C. vulgaris* isolates [34–36]. The antifungal effectiveness has been explored for various extracts of some of the lichen species such as *Ramalina roesleri*, *Usnea longissima*, *Parmelia reticulata*, and *Stereocaulon himalayense*. As a result, the extracts observed to have antifungal activity to a significant extent [38]. In addition, lichen-derived products were evaluated for the management of pests and their herbicidal as well as fungicidal activities have been recognized [39].

In Mediterranean civilizations, the most common colors violet and purple were obtained from mollusks and lichens with minute disadvantage of poor light-fastness abilities [40, 41].

Some specific mordants (especially salts of Cu, Fe, Cr, Al, Sn, Pb, etc.) are essentially pH dependant which give desirous colors such as purple, variables of red and orange, with certain dyes and pigments [42, 43]. *Rocella tinctoria* and *R. fuciformis* were most popular lichens which were documented to occur in the Cape Verde Islands (West Coast of Africa), South and Central America, East Indies, Madagascar, and Europe. In France, the lichen *Pertusaria dealbescens* Erichs was reported to have dyeing potential. Consequently, few species of the genus *Rocella* and *Ochrolechia tartarea* Linn. were also indicated the utilization of derived dyes and pigments in Scandinavian and Celtic countries [42, 44–46].

Table 1.2 *In vitro* MIC values (mg/ml) for various lichen species with respect to tested bacterial strains. (Shrestha 2014 Reproduced from Ref. No. [37] with permission. Copyright© Taylor & Francis, 2014).

Bacterial strains	***E. coli***		***P. aeruginosa***		***S. aureus***		**MRSA**	
Selected lichen species	**A**	**M**	**A**	**M**	**A**	**M**	**A**	**M**
Alectoria imshaugii	–	–	31.25	15.6	62.5	62.5	250	125
A. sarmentosa	–	–	31.25	15.6	62.5	31.25	125	62.5
Bryoria fuscescens	–	–	125	–	125	–	500	–
Cladonia furcata	–	–	250	–	500	–	500	–
Evernia prunastri	–	–	31.25	125	62.5	250	125	500
E. strum catawbiense	–	–	250	–	125	–	500	–
Flavocetraria nivalis	–	–	31.25	15.6	62.5	31.25	500	62.5
Hypogymnia physodes	–	–	62.5	250	62.5	62.5	62.5	250
Letharia columbiana	250	–	125	–	125	500	31.25	125
L. vulpina	125	500	125	500	3.9	15.6	31.25	125
Lobaria pulmonaria	–	–	–	–	–	–	–	–
Masonhalea richardsonii	–	–	250	500	125	125	125	250

(*Continued*)

Table 1.2 *In vitro* MIC values (mg/ml) for various lichen species with respect to tested bacterial strains. (Shrestha 2014 Reproduced from Ref. No. [37] with permission. Copyright© Taylor & Francis, 2014). (*Continued*)

Bacterial strains	***E. coli***		***P. aeruginosa***		***S. aureus***		**MRSA**	
Selected lichen species	**A**	**M**	**A**	**M**	**A**	**M**	**A**	**M**
Parmelia sulcata	-	–	125	–	250	–	125	–
Parmotrema reticulatum	–	–	250	–	250	–	250	–
Peltigera aphthosa	–	–	250	–	–	–	–	–
Platismatia glauca	–	–	250	–	500	–	500	–
Ramalina sinensis	–	–	15.6	250	15.6	–	62.5	–
Rhizoplaca chrysoleuca	–	–	7.8	125	7.8	250	15.6	500
R. haydenii	–	–	3.9	31.25	15.6	31.25	15.6	62.5
R. idahoensis	–	–	7.8	31.25	15.6	125	15.6	125
R. marginalis	–	–	7.8	125	7.8	250	7.8	500
R. melanophthalma	–	–	15.6	62.5	15.6	125	31.25	250
R. peltata	–	–	15.6	62.5	31.25	250	31.25	250
Sphaerophorus globosus	–	–	7.8	31.25	62.5	500	62.5	500
Thamnolia vermicularis	–	–	31.25	125	125	500	500	500

(*Continued*)

Table 1.2 *In vitro* MIC values (mg/ml) for various lichen species with respect to tested bacterial strains. (Shrestha 2014 Reproduced from Ref. No. [37] with permission. Copyright© Taylor & Francis, 2014). (*Continued*)

Bacterial strains	***E. coli***		***P. aeruginosa***		***S. aureus***		**MRSA**	
Selected lichen species	**A**	**M**	**A**	**M**	**A**	**M**	**A**	**M**
Tuckermannopsis ciliaris	–	–	125	–	62.5	250	250	500
Umbilicaria americana	–	–	500	–	500	–	–	–
U. mammulata	–	–	500	–	–	–	–	–
Usnea hirta	–	–	3.9	15.6	7.8	31.25	7.8	62.5
U. strigosa	–	–	3.9	31.25	7.8	32.5	15.6	250
Vulpicida canadensis	250	–	15.6	15.6	15.6	62.5	31.25	125
Xanthoparmelia chlorochroa	–	–	3.9	62.5	7.8	62.5	31.25	–
X. coloradoensis	–	–	7.8	62.5	7.8	250	15.6	500
X. wyomingica	–	–	15.6	15.6	15.6	62.5	62.5	500

A, acetone extract; M, methanolic extract; – , not considerable.

Neurodegenerative diseases are the diseases associated with the central nervous system that alter chiefly shape and functionality which strike on various dynamics of our body, for instance, talking, breathing, movement, heat activities, etc. Some lichen species have the potential to treat the mentioned diseases [47]. In our traditional medicine system as well as in the new system of medicine, nature-derived products have proved to be useful for medical and incurable diseases. Thus, nature-derived products have shown curing abilities to treat diabetic and neurological disorders [33–36, 47].

Enzyme inhibition activity was reported not only in derived secondary metabolites but also have been observed in solvent-based extracts from various species of lichenized fungi responsible for the effectiveness to have medicinal properties. For example, enzyme inhibition activity has been found effective toward trypsin, lipase, amylase, urease, tyrosinase, β-glucoronidase, cyclooxygenase, prolyl endopeptidase, lipoxygenase, aromatase, monoamine oxidase, thioredoxin reductase, xanthine oxidase, and many more [36–38]. Lichen-derived compounds such as usnic acid and its derivatives like physodic acid, lobaric acid, atranorin, evernic acid, zeorin, protolichestrinic acid, salazinic acid, and methyl β-orcinolcarboxylate were found to have inhibitors of some disease responsive enzymes [35, 36, 48]. However, lichens contain bioactive constituents in majority and they are under considerable attention within scientific community. Yet, more researches are needed on a larger scale to execute new dimension on lichen epidemics.

1.5 Conclusion and Future Outlook

Traditionally, lichens as whole and their extracts were used to treat various diseases and to dye the clothings around the globe since thousands of years. Lichens, having variable morphology and growing nature in clean ecosystem, possess indicating arrangements to the various environmental factors. They show sensitivity to the change in a small way. This seems to be because their chemical diversity is found different due to climatic phase such as variable temperature, altitude, and climate, and so, are called as universal environmental indicators. Many active derived ingredients from lichen species are found "lead" chemical structures and possess diverse biological properties such as antimicrobial, antiprotozoal, anticancer, antiviral, antioxidant, anti-inflammatory, and antidiabetic activities. Additionally, lichens cannot be potentially sidelined for pest related management, and they can be a better alternative to the synthetic counterparts. However, lichens pay much attention between scientific communities, yet they must be explored further so that they may be utilized for the social as well as economic benefits to our society to increase the natural product–based economic enhancements.

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