A Review on Nutritional Composition, Phytochemistry and Pharmacological Properties of Lichen

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Abstract

Lichen shows a symbiotic relationship between fungi and algae. Lichens are slow-growing organisms, but they are found in different kinds of habitats throughout the world. Lichens are renowned for their diverse application; particularly in traditional medicine, due to the presence of active substances within them. Lichens are an important source of natural resources; they are used in various aspects of human life, including as food, fodder, dyes, perfume, spice, and for various miscellaneous purposes. Few species of lichens are identified as a source of food. Though many researchers are concerned about lichens because of their secondary metabolites, there has been limited exploration of research specifically focused on edible lichens. This review focused on the uses of lichen as food and analyzed their nutritional value and health benefits of secondary metabolites of lichens. So, these may provide new opportunities to the researchers for the research on edible lichen and medicinal properties derived from lichen. Theoretically, it is well known that lichens are rich in nutrition, their extracts and active substances also have various health benefits including anticancer, anti-inflammatory, antioxidant, antidiabetic, antibacterial, and antifungal activities, etc. However, the nutrient compounds that are derived from edible lichens and the activity of their active substances remain unsolved. Therefore, more work is needed on the edibility of lichens. This review may provide new directions to the researchers on lichen research in the future.

***Keywords*:** Edible lichen; Lichen; Nutritional value; Secondary metabolites.

1. Introduction

Lichen thallus appears as a single organism, but actually they are in symbiotic association with fungi and algae. The fungal partner of lichen is known as mycobiont, they absorb minerals and moisture from the environment and the algal partner is known as phycobiont or photobiont, they produce food. Lichens are a unique division of the plant kingdom. The division lichen is comprised of 8 classes, 39 orders, 115 families, 995 genera, and 19,387 species at the global level [1].

Lichen shows a large scale of habitat preference; from desert to tropical rainforest [2]. Lichens can grow on all types of substrate, such as on bark (corticolous), twig (ramicolous), evergreen leaves (foliicolous), moss (muscicolous), wood (lignicolous), rock (saxicolous), soil (terricolous) [3, 4]. Mainly the lichens have three types of growth forms; such as crustose, foliose, and fruticose lichen (Table 1).

Lichens are widely used as biomonitoring agents. Lichens indeed play a crucial role in serving as indicators for the detection of air pollution and environmental changes [4]. So, it is well known as a bioindicator because of its sensitivity to environmental conditions, which makes them valuable indicators of the health of ecosystems and air quality. Apart from their environmental role, lichens are used globally for various purposes, including medicine, food, fodder, dye, spice, perfume, and various miscellaneous applications [5, 6]. Lichens are also well known for secondary metabolite production. The secondary metabolites are isolated from different species of lichen which have different kinds of biological activities [7].

Table 1: Types of Lichen [3, 8]

Crustose lichen		• Crust-like appearance • Slowest growing • Yellow-green in colour. (eg. *Rhizocarpon* sp.)
Foliose lichen		• Leaf-like appearance • Development quite slow. (eg. *Parmelia* sp.)
Fruticose lichen		• Shrub-like appearance • Attached to the substrate by holdfast. (eg. *Cladonia* sp.)

2. Lichen Use as Food

Lichens play a crucial role as a significant food source for a variety of animals; such as caterpillars, mites, slugs, snails, etc. From the earliest period, lichens have been used as food by different human cultures (Table 2). In America, Europe, Asia, and Africa lichens are eaten by people as food. Many people have used lichen as food regularly [9].

The 'Limbu' community of Nepal uses a total number of 8 species of lichen as food. These 8 species of edible lichens are foliose and fruticose types belonging to the family Parmeliaceae and Ramalinaceae [10]. Lichens are used as food because they are rich in proteins, vitamins, enzymes, and polysaccharides. Though numerous lichen species exist globally, among them only a few selected species of lichen are recognized as edible lichen and capable of providing nutrition. But there are certain groups of lichens; such as wolf lichen, powdered sunshine lichen, and ground lichen, are considered poisonous groups of lichen and are not used as edible lichen [11]. About 15 types of edible lichens are found in China, which can be used in different kinds of food processing [12]. Probably *Cetraria islandica* is a lichen species which is first used as human lichen food [13].

Table 2: Uses of Lichen Species as Food

Lichen species	Growth forms	Places	Mode of uses	References
Bryoria fremontii (Tuck.) Brodo & D. Hawksw.	Fruticose	North America	Soup, Traditional food	[14, 15]
Cetraria islandica (L.) Ach.	Fruticose	Estonia, Finland, Iceland, Italy, Northern Europe, Norway	Bread,Flavouring agents, Porridge, Pudding, Salad, Soup	[11, 15, 16, 17]
Cladonia rangiferina (L.) Weber.	Fruticose	Finland, Norway, Sweden	Beverages, Food supplements, Ingredients of bread, Tea	[15]
Cladina rangiferina (L.) Nyl.	Fruticose	China	Salads	[11]
Dermatocarpon miniatum (L.) W. Mann.	Fruticose	China	Dishes, Soups	[11]
Everniastrum cirrhatum (Fr.) Hale ex Sipman	Foliose	India	Flavouring agents, Spices, Vegetables	[9, 11]
Flavocetraria nivalis (L.) Karnefelt & A. Thell	Fruticose	Peru, Poland	Tea	[11,18]
Lethariella cashmeriana Krog	Fruticose	China	Tea	[11]
Lethariella cladonioides (Nyl.) Krog	Fruticose	China	Beverages, Tea, Wines	[11, 19]
Lobaria pulmonaria (L.) Hoffm.	Foliose	China	Dishes, Soups	[11]
Lobaria retigera (Bory) Trev.	Foliose	Canada, China	Dishes, Soups, Tea	[11]
Parmelia paraguariensis Lynge	Foliose	Mauritania	Tobacco	[9]
Parmelia perlata (Huds.) Ach.	Foliose	India	Spice	[15, 20]
Parmotrema tinctorum (Despr. ex Nyl.) Hale	Foliose	Kuwait, Oman, Western Saudi Arabia	Spice	[9]
Platismatia glauca (L.) W.L. Culb. & C.F. Culb.	Foliose	India	Spices	[11]
Ramalina conduplicans Vain.	Fruticose	Nepal	Dishes	[11, 21]
Roccella montagnei Bél.	Fruticose	Coromandel Coast, Southeast	Food and folk medicine	[15]

		Coast of India, Tamil Nadu		
Thamnolia subuliformis (Ehrh.) W. L. Culb.	Fruticose	China	Beverages, Dishes, Tea, Wines	[11]
Umbilicaria crustulosa (Ach.) Lamy	Foliose	Asia, Japan, Korea	Traditional food	[15, 22]
Umbilicaria esculenta (Miyoshi) Minks	Foliose	China, India, Nepal	Food, Restorative medicine	[15]
Umbilicaria muehlenbergii (Ach.) Tuck.	Foliose	North America	Soup	[9]
Usnea florida (L.) F.H. Wigg.	Fruticose	Southern and Western British	Tea	[15]
Usnea longissima Ach.	Fruticose	China	Dishes	[11]

2.1. Nutritive Value of Lichen

Lichens are preferred as a food source in Africa, China, Europe, Japan, Nepal, and India [23]. Lawrey [24] reported that lichen produces natural organic compounds like primary and secondary metabolites. Primary metabolites are produced intracellularly and secondary metabolites are produced extracellularly [9].

2.1.1. Primary Metabolites of Lichen

Most of the primary metabolites of lichen are water-soluble. Primary metabolites can be extracted from lichen through boiling water [25]. These metabolites are produced by both fungal and algal partners within the lichen symbiosis. Additionally, many of these primary metabolites are not only found in lichen but also in fungi, algae, and higher plants [26].

Primary metabolites of lichen include amino acids, amines, peptides, proteins, polyols, polysaccharides, carotenoids, vitamins, chitin, enzymes, and pectins [5, 11, 26, 27].

Lichens are nutritionally essential due to their high carbohydrate content (53.2-79.08%), fibre (5.386-16.36%), and low-fat content (1.3-6.5%) (Table 3). Lichens are also good sources of protein (5.95-16.2%) and are rich in mineral elements [23]. *Cladonia stellaris* contains approximately 3.1% protein of its dry matter,78.4% hemicelluloses, 1.7% cellulose, and 2.0% water-soluble carbohydrates [28]. Table 3 indicates that lichens include a variety of important nutrients necessary for life and normal physiological activities in the human body.

Table 3: Proximate Compositions of Some Edible Lichens (%) [11]

Lichen species	Total carbohydrate	Water soluble carbohydrate	Cellulose	Hemicellulose	Lignin	Protein	Fiber	Fat	Ash
Cetraria islandica	82.5	1.9	3.9	25.8	50.9	NF	NF	NF	NF
Parmotrema pseudotinctorum	53.2	1.1	2.1	21.4	28.6	16.2	12.0	6.5	8.9
Parmotrema tinctorum	72.13	1.8	3.5	18.6	48.23	11.3	16.36	1.3	6.15
Ramalina conduplicans	79.08	1.3	4.2	44.5	29.08	5.95	5.86	2.1	4.01
Ramalina hossei	59.9	0.8	3.8	19.5	35.8	8.8	10.8	3.2	12.1

(NF* Not found)

Theoretically, lichens have higher nutritional value because of their high fiber content, low-fat content, and a good source of protein. Lichens obtain most of the mineral elements from the air because they can accumulate air pollutants easily [29]. Meli et al. [30] reported that arsenic, cadmium, lead, and other toxic elements are present in *Cetraria islandica*, but stated that the low quantities are not dangerous to human health. In a separate study, Glew et al. [31] investigated the proximate composition of an African food named "Yari", primarily composed of *Rimelia reticulate*. They reported comparatively reduced protein content (5.31%) in "Yari". However, the essential amino acid percentages in "Yari" are notably higher than the protein content. It is confirmed that lichens are a potential source of high-quality protein. Despite the less amount of nutritional value in fibre, it is beneficial for intestinal health. Intake of fibre in a regular diet can reduce the chances of certain chronic diseases, such as diabetes, obesity, and heart diseases. Furthermore, the high ash content in lichens indicates that lichens are rich in mineral elements [32].

2.1.2. Secondary Metabolites of Lichen

Secondary metabolites represent a significant group of organic compounds that are prominently found in lichen [26]. All the secondary metabolites of lichen are originated from fungal partners. The diversity of secondary metabolites in lichens is extensive, with more than 800 identified compounds [27]. Secondary metabolites of lichen are generally poorly soluble in water, they can be extracted using organic solvents [33]. The secondary metabolites of lichen are in crystal form, these forms are very stable. The old herbarium of lichen specimens showed no remarkable changes in the concentration of secondary metabolites [34].

Secondary metabolites of lichen are classified based on their chemical structures and biosynthetic origins [26, 35]. Secondary metabolites of lichen are produced through three chemical pathways (Table 4) [26]. Secondary metabolites of lichen are also known as lichen acids (Table 5).

Table 4: List of Biosynthetic Pathways and Secondary Metabolites [7, 26]

Biosynthetic pathways	Secondary metabolites
Acetyl polymalonyl pathway	Anthraquinone, Chromones, Depsides, Depsidones, Dibenzofurans, Xanthone
Shikimic acid pathway	Pulvinic acid and its derivatives, Terphenylquinones
Mevalonic acid pathway	Steroids, Terpenes

Table 5: Example of Secondary Metabolites (Lichen Acids) [26]

Secondary metabolites	Example
Anthraquinones	Emodin, Parietin
Chromones	Lepraric Acid
Depsides	Atranorin, Evernic Acid, Gyrophoric Acid, Lecanoric Acid, Thamnolic Acid, Umbilicaric Acid
Depsidones	Fumarprotocetraric Acid, Protocetraric Acid, Physodic Acid, Stictic Acid
Dibenzofurans	Alectosarmentin , Usnic Acid
Pulvinic Acid Derivatives	Pulvinic Acid, Vulpinic Acid
Steroids	Brassicasterol, Ergosterol, Lichesterol
Terpenes	Limonene, Phytol, Zeorin
Terphenylquinones	Polyporic Acid, Thelephoric Acid
Xanthones	Norlichexanthone, Thiophanic Acid

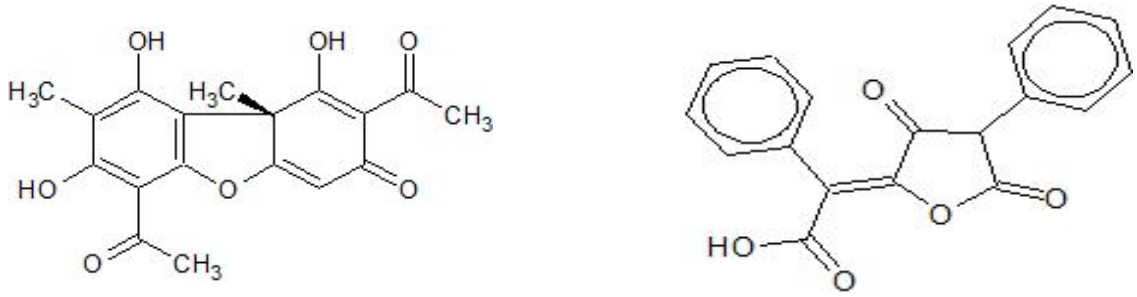
Some lichens are rich in calcium and iron. The level of calcium and iron in lichen is higher than in cereals and green leafy vegetables [36]. Some fruticose lichen contains a small amount of protein, but some foliose lichen like *Peltigera* sp., *Lobaria* sp. have more protein [37]. Different studies have shown that lichen also contains some vitamins. *Cladonia rangifernia* has ergosterol more than other lichens. *C. rangifernia* which has been collected from Upsala has a small amount of Vitamin D [13].

2.2. Disadvantages of Using Lichens as Food

It has been believed that lichens may become a source of popular food due to their nutritional value, but this has not happened. Though lichens are repeatedly used as food by different communities of people, many people have used lichen as a source of good food regularly, but it varies among different communities and regions. Some cultures may have historical or traditional uses for certain lichen species, but these practices might not be well-documented.

However, there are some problems with using lichen as a source of food because of its small size, slow growth rate, and inadequate information about the biological compositions of lichen and the features of its chemical constituents [9]. The presence of secondary metabolites and carbohydrates in lichen irritates the digestive tract and they are also difficult to digest. The secondary metabolites of lichen are acidic in nature [38].

There are a few lichen compounds like usnic acid and vulpinic acid (Fig 1) that have been detected as poisonous. Intake of significant amounts of such compounds could be lethal for human beings. Some compounds are very bad tasting and toxic in nature; they cause harmful effects if ingested for a long period. There is another drawback of using lichen as food, especially for humans because lichen can absorb pollutants (toxic substances) from the environment [9].



(a) (b)

Fig 1: Chemical Structure of Usnic acid (a) and Vulpinic acid (b)

People have used lichen in different kinds of food preparation and made them edible by eliminating the chemical components of secondary metabolites. People have used different techniques. People of North America, Europe, and India boil the lichen before use which helps to remove the chemical components and make them edible. Sometimes lichens are soaked in ash water because it is alkaline in nature which helps in removing the chemical components of lichen [9].

3. Phytochemistry and Pharmacological Properties of Lichen

The secondary metabolites that are found in lichens may indeed play an important role in the pharmaceutical industry. Lichen secondary metabolites have anticancer, antifungal, anti-inflammatory, antimicrobial, and antioxidant activities.

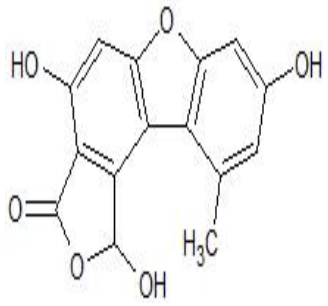
A summary of pharmaceutical activities in several lichen species is given in Table 6, and the chemical structure of some common lichen compounds is given in Fig 2.

Table 6: Lichen Compounds and their Pharmaceutical Activities [26, 39]

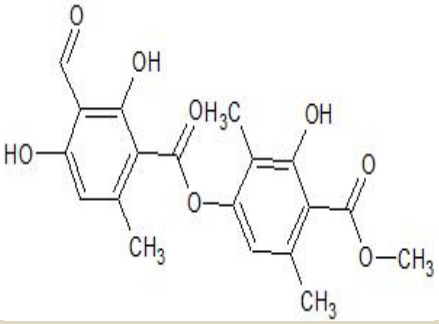
Lichen compounds	Studied activities	Lichen species	Growth forms
Alectosarmentin	Antibacterial activity	*Alectoria sarmentosa* (Ach.) Ach.	Fruticose
Atranorin	Anticancer, antidiabetic, anti-inflammatory, antimicrobial, anti-neurodegenerative, antitumor, and antioxidant activities	*Hypogymnia tubulosa* (Schaer.) Hav.	Foliose
Brassicasterol	Antioxidant activity	*Xanthoria parietina* (L.) Th. Fr.	Foliose
Emodin	Antiviral activity	*Xanthoria elegans* (Link) Th. Fr.	Foliose
Ergosterol	Antifungal activity	*Physcia stellaris* (L.) Nyl.	Foliose
Evernic Acid	Anticancer, antifungal, antimicrobial, and antioxidant activities	*Evernia prunastri* (L.) Ach.	Foliose
Fumarprotocetraric Acid	Antibacterial, anticancer, antifungal, antioxidant, and	*Cetraria islandica* (L.) Ach.	Foliose

	neuroprotective activities		
Gyrophoric Acid	Antibacterial, anticancer, antidiabetic, antioxidant, antitumor, and cytotoxic activities	*Lasallia pustulata* (L.) Merat	Foliose
Lecanoric Acid	Antibacterial, anticancer, antidiabetic, antifungal, anti-inflammatory, antioxidant, and antitumor activities	*Hypocenomyce scalaris* (Ach.) M. Choisy	Squamulose
Lepraric Acid	Used as a chemotaxonomic marker	*Lepraria* sp.	Crustose
Lichesterol	Anticancer, anti-inflammatory, antimicrobial, antioxidant, and antipsychotic activities	*Usnea longissimi* Ach., *Lobaria pulmonaria* (L.) Hoffm., *Xanthoria parietina* (L.) Th. Fr., *Ramalina Africana* (Stein) C. W. Dodge	Fruticose, Foliose
Limonene	Antifungal, and antimicrobial activities	*Evernia prunastri* (L.) Ach.	Fruticose
Norlichexanthone	Antimalarial activity	*Lecanora symmicta* (Ach.) Ach.	Crustose
Parietin	Antioxidant activity	*Xanthoria parietina* (L.) Th. Fr.	Foliose
Physodic Acid	Antibacterial, anticancer, antifungal, anti-inflammatory, anti-neurodegenerative, and antioxidant activities	*Hypogymnia physodes* (L.) Nyl.	Foliose
Phytol	Antimycobacterial activity	*Anaptychia ciliaris* (L.) Flot.	Foliose
Polyporic Acid	Antileukemic activity	*Sticta coronata* Müll. Arg.	Foliose
Protocetraric Acid	Antibacterial, anticancer, antifungal, and antioxidant activities	*Flavoparmelia caperata* (L.) Hale.	Foliose
Pulvinic Acid	Antioxidant activity	*Candelariella vitelline* (Hoffm.) Müll. Arg.	Crustose
Stictic Acid	Anticancer, antimicrobial, and antioxidant activities	*Lobaria pulmonaria* (L.) Hoffm.	Foliose
Thamnolic Acid	Antibacterial, antifungal, and antituberculosis activities	*Thamnolia vermicularis* (Sw.) Schaer.	Fruticose
Thelephoric Acid	Antioxidant activity	*Lobaria insidiosa* (Müll. Arg.) Vain.	Foliose
Thiophanic Acid	Fungicidal activity	*Lecidella elaeochroma* (Ach.) M. Choisy	Crustose
Umbilicaric Acid	Antimicrobial, and antioxidant activities	*Umbilicaria polyphylla* (L.) Baumg.	Foliose
Usnic Acid	Analgesic, antibacterial, antidiabetic, antifungal, anti-inflammatory, antimitotic, antioxidant, antiprotozoal, antipyretic, antitumor, antiviral, and hepatotoxic activities	*Usnea* sp.	Fruticose
Vulpinic Acid	Anticancer, and antimicrobial activities	*Vulpicida pinastri* (Scop.) J. -E. Mattsson	Foliose

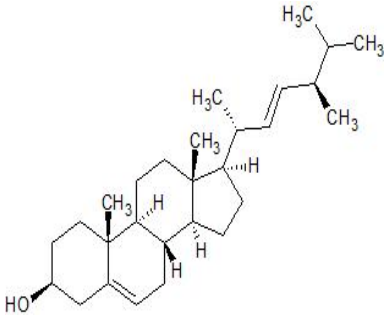
		& M.J. Lai	
Zeorin	Antibacterial, antidiabetic, antifungal, and antioxidant activities	*Lecanora frustulosa* (Dicks.) Ach., *Parmeliopsis hyperopta* (Ach.) Vain., *Protoparmeliopsis muralis* (Schreb.) M.Choisy	Crustose to subfruticose, Foliose, Crustose



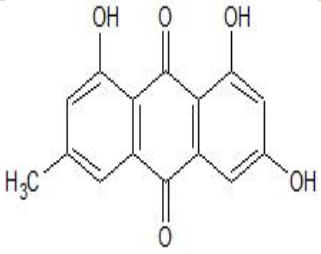
Alectosarmentin



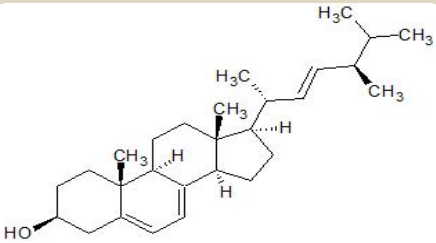
Atranorin



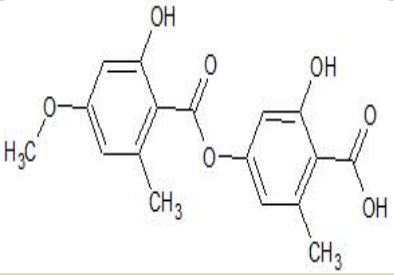
Brassicasterol



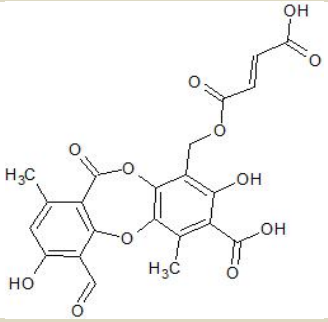
Emodin



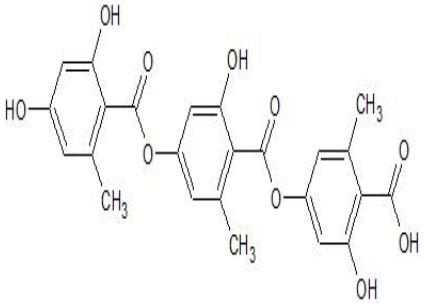
Ergosterol



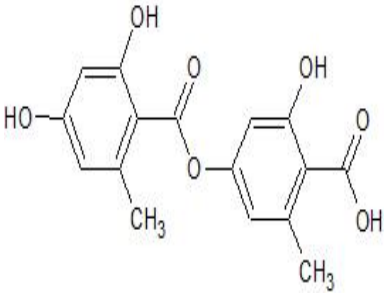
Evernic Acid



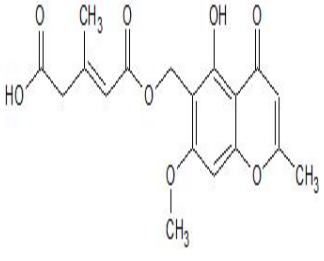
Fumarprotocetraric Acid



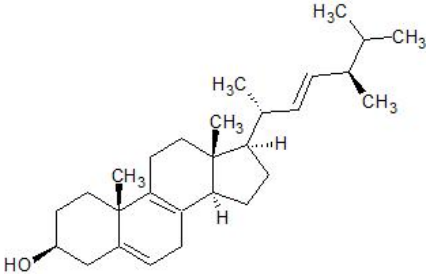
Gyrophoric Acid



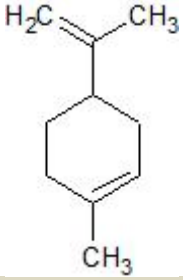
Lecanoric Acid



Lepraric Acid



Lichesterol



Limonene

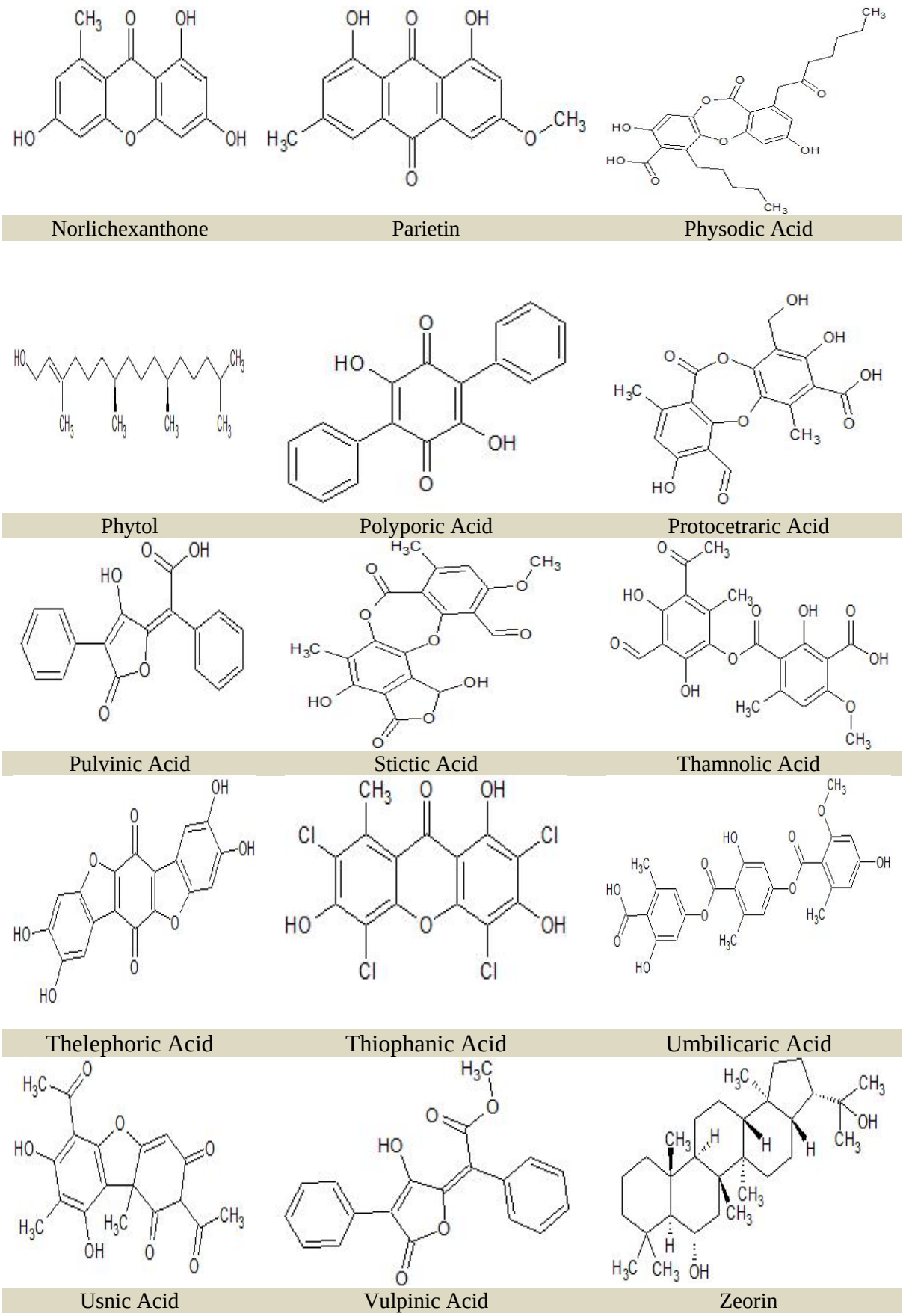


Fig 2: Chemical Structure of Some Common Lichen Compounds

All lichen compounds can be broadly classified into three groups; such as aliphatic lichen substances, aromatic lichen substances, and carbohydrates. Aliphatic substances include acids, zeorin compounds, and polyhydric alcohols. Aromatic lichen substances include depsidones, depsides, nitrogen-containing compounds, pulvic acid derivatives, etc. and carbohydrates are polysaccharides [40]. Three main types of polysaccharides (beta-glucans, alpha-glucans, and galactomannans) are found in different kinds of lichen species [5, 41]. Polysaccharides also have some biological activities, such as anti-tumor, anti-inflammatory, or immunomodulating activity [5, 42].

4. Conclusion

Lichen shows a special symbiotic relationship between algae and fungi. Lichens are unique organisms, because of their different pharmacological activities and produce different kinds of bioactive compounds. Except of their biological activities, research on the nutritional analysis of lichens has been neglected by researchers due to their slow growth rate and there are many difficulties in culturing them *in-vitro*. Theoretically, it is known that many lichens have nutritive value but research on edible lichens is still needed to establish their nutritional potential. A limited number of edible lichen species have been identified. There is no evidence about the species of crustose lichens which can be used as food. For this investigation, more research is needed. The active compounds of lichen have many health benefits, such as anticancer, antidiabetic, anti-inflammatory, antimicrobial, and antioxidant activities. It has been proven that many lichen species have health benefits but most of them have not been reported for their nutritive value. To reduce such problems in the use of edible lichens as a source of nutrition and medicines, further research is needed.

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