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Parmotrema species and their potential health benefits: A comprehensive review

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ABSTRACT

Plants contain material that helps treat different kinds of body disorders due to the presence of various compounds in them. Lichens possess medicinal effects that show very beneficial properties in terms of health. Lichens are symbiotic organisms that are formed on the surface of plants and grow by a combination of algae and fungi. Different species of lichens grow worldwide and some of them are discussed in this review, but the main focus is on *Parmotrema perlatum* and *Parmotrema* genus as compared to others. They grow mostly in cold and dry areas as well as in mountainous regions and rocks around the world. These lichens contain phenolic compounds (flavonoids, polyphenols, tannins, pulvinic acid derivatives), terpenoids (e.g., triterpenes), and polyketides (usnic acid, diffractaic acid, lecanoric acid, atranorin, glycosides, proto-lichesterinic acid, azolitmin, spaniolitmin, orcin, salazinic acid, tridecyl myristate). Nutritionally they also contain polysaccharides, vitamins, minerals and many others which possess many positive effects on health. Phenolic compounds present in these lichens possess anti-tyrosinase activity and slow down the process of melanin synthesis. Lichens are contributors to the treatment of wounds, elevated blood glucose, elevated blood pressure, immunity boosting, killing microbes, certain infections caused by bacteria and viruses like tuberculosis, gastrointestinal tract problems, regulating normal breath, dilating airways and blood vessels to reduce pressure. Lichens contain compounds that reduce oxidative stress in the body caused by free radicals and lower the risk of mental problems, cell proliferation, cardiovascular diseases, diarrhea, and skin problems. Lichens are essential for the cure of renal diseases, uric acid and inflammation of joints and bronchi.

1. Introduction

Medicinal plants are the plants that are used to treat different ailments. These plants can be traditionally consumed directly or in any other form, like paste, suspension, etc. Medicinal plants have been used for centuries and are considered an important part of modern medicine nowadays because they contain bioactive substances that are important in the treatment of inflammation, oxidative stress and bacterial infection (Matra *et al.,* 2025; Rafiq, et al., 2024; Khan et al., 2024;). Different compounds present in the plants are important in drug formation. Almost four out of five individuals rely on traditional medicines for their overall health and well-being. They are also used to treat neuronal disorders (Karabacak et al., 2025; Kunu et al., 2025; Sukhonthara & Thipnate, 2026). Medicinal plants contain a huge number of active compounds to treat multidrug-resistant microbes (Salmerón-Manzano *et al.*, 2020). Compounds present in different plants are naturally used to improve health status, reduce death rate and health expenditure (Kebede *et al.*, 2021; Babou, Chakit and Sqalli-Houssaini, 2026; Rashid et al., 2024). Bioactive compounds present in medicinal plants are also considered effective as they diminish the side effects of higher levels

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of cisplatin (Abdelhiee *et al.,* 2025; Ullah R, 2024). Phytochemicals present in medicinal plants make them effective for treatment in different ailments (Merdana *et al.,* 2025). These plants possess a longer and more permanent treatment without adverse side effects to our body as compared to synthetic drugs used for curing diseases (Bagheri *et al.,* 2024). In ancient times, these plants were mostly used to treat diseases and illnesses and for the betterment of human lives. Most of the aromatic plats due to their chemical composition and presence of flavonoids, essential oils and other active substances are considered safe for use as therapeutic substances (Ullah, 2024). Today, most of the plants are used as medicinal plants because these are more economical than drugs. Most plants are generally safe, but some can have harmful effects on health if consumed directly. Nowadays scientists and researchers work to obtain alternatives with less side effects named as botanicals and their bioactive compounds for different disease treatment (Alawfi, 2025).

Lichens are forms of life that are widely found on earth. Lichens are not a single organism but two or more organisms combined to form lichens (Senthilkumar, 2015). The coordinated relationship between algae and fungi produces lichens. It is the relation between a photobiont, which is algae and a mycobiont, which is known as fungi. An alga is responsible for photosynthesis while the fungus is important in making the body structure of lichen known as thallus. Thallus is useful for the attachment of these lichens to the concrete, hard soil, rock, and trees where these lichens are usually found (Roziaty *et al.*, 2023). Approximately, 30,000 lichen species are found worldwide. Out of them, 2040 species of lichens are found in India, 5500 in North America, 2678 in Colombia, and about 6000 in Canada, and most of them are found in many other regions of the world (Manzitto-Tripp *et al.*, 2022). The lichens belonging to the *Parmeliaceae* family are vaster as lichen have 80 genus and more than 2700 species (Senthilkumar, 2015). *P. perlatum* is one of the most important species of *parmiliaceae* family lichens and is commonly used in India for various purposes. It is known as canary moss, Mangalore spice, black stone flower, kalpasi, shipal, shaliya, charila, pathar phool, and dagad phool (Neelima *et al.*, 2022).

Lichen of the *Parmotrema* genus thrive best in humid regions with temperatures ranging from 21 to 25°C and humidity levels between 50% and 60%. (Ureña-Vacas *et al.*, 2022). *P. perlatum* grows at an altitude of 1810-2700 m above sea level (Roziaty *et al.*, 2023). *P. perlatum* is the species that grows on old trees, walls, rocks, and hilly areas in temperate regions of the Northern and Southern Hemispheres of Asia, Europe, Africa, North America, Central America, South America, Himalayas, Kashmir, Australia, and New Zealand (Stelate *et al.*, 2022). It can be reproduced by spore-formation or by dispersion through wind (Hussain *et al.*, 2021). *P. perlatum* is a greenish-grey colored lichen known as foliose lichen that has round lobes. It can be recognized easily through its wider lobes. These are irregularly branched (7.0 cm broad) and overlapped, 4.0-7.0 mm wide. Cilia are black, simple (0.20-)0.50–1.00 × 0.02(–0.10) mm diameter. It is most commonly used in Ayurveda and traditional medicines in India (Stelate *et al.*, 2022). *P. perlatum* has a variety of secondary metabolites such as flavonoid, terpenoid, saponins, atranorin, lecanoric acid, orcin, erythrolein, azolitmin, spaniolitmin, tannins, glycosides, steroidal aglycone, oligodynamic elements usnic acid, diffractaic acid, atronin, salazinic acid, tridecyl myristate, proto-lichesterinic acid, 3-keto oleanane, icosan-1-ol, lecanoric acid, labdane type diterpenoid (permelandone), and lano-2-en-type triterpene (permelanostene) etc. (Hussain *et al.*, 2021).

The reason for its use in medicine is that this lichen contains naturally occurring bioactive compounds such as anti-oxidants, compounds that are useful for lowering the level of free radicals in the body and protecting the body from oxidative stress (Johnmark and Kinyi, 2021). They are also very helpful in reducing the risk of disease by blocking the formation of new blood vessels from the previous blood vessels (Ulus, 2021), and act as anticoagulants (compounds that can reduce the risk of blood clotting), antimicrobial agents that regulate the growth of bacteria (Sana *et al.*, 2024) and antibiotic agents (to kill or inhibit the activity of different types of microorganisms and certain bacteria to prevent the patient from microbial or bacterial infection) (Roser *et al.*, 2022). Lichens exploit a vast variety of biological actions like antimycotic in which different compounds are used to treat fungal infection. Lichens express two types of properties, fungicidal properties and fungi static properties, which kill fungi or lower the ergo sterol level in the body respectively (Al Hujran *et al.*, 2022). Also, acts as an antipyretic *i.e.*, agent that is closely related to the maintenance of body temperature, and treats fever by lowering the temperature up to the normal body temperature that is about 37°C, antiviral, antifungal, anti-inflammatory (Nguyen *et al.*, 2020), and anti-proliferative agent (Oliveira-Alves *et al.*, 2020). Cytotoxic is the most widely used technique in cancer patients for the protection of the body cells from toxic substances in the drugs or the process by which the body's immune system responds to the cells like tumor cells or other infected cells and kills them. By this procedure, the cell may be destroyed completely or can shrink in size (Arnhold, 2023) and have an analgesic (relieve pain) effect (Neelima *et al.*, 2022). *P. perlatum* is used in the treatment of gastrointestinal, respiratory, and vascular disorders, dysentery, dyspepsia, and hepatic problems. *P. perlatum* is traditionally used in powder form with a dosage range of 1–3 gm or can be used as a paste with a range of 30 to 40 mL (Hussain *et al.*, 2021). Different types of plants have been used for centuries to treat various types of diseases and wounds which are called medicinal plants just like these lichens also contain a high amount of biologically active compounds in them (Sharma *et al.*, 2021).

P. perlatum is one of the lichen that is very helpful for patients with hyperglycemia, narrowing of arteries, cardiovascular disease, breathing problems, tuberculosis, skin problems, inflamed joints, high blood pressure, diarrhea, inflammation of bronchi, airway congestion, wound healing, infections, neuroblastoma (a type of cancer that arises in neuroblasts) (Tartouga *et al.*, 2022), inflammation and digestive system problems (Dwarakanath *et al.*, 2022). *P. perlatum* is used in the textile industry for dyeing purposes. It may decrease the period of dyeing and can accelerate or enhance the dyeing process of silk. *P. perlatum* is the main ingredient in pharmaceuticals, herbal medicine, cosmetics, and perfume-making industries (Mohammadi *et al.*, 2022). This review provides information about the properties of *P. perlatum* lichen and details about their nutritional content and the functions of different metabolites present in them. Data collection is done by using the previously five-year published articles with the help of different keywords like "lichen", "*P. perlatum*", "kalpasi", "bioactive compounds", "melanin", "cell death pathway", "medicinal plant", "chemical structure", "health effect", "black stone flower", "dagad phool", "inflammation", "cancer", "respiratory problems" and "digestion".

Lichens yield biomass, which is a byproduct produced in the presence of oxygen and ammonia (Pichler *et al.*, 2021). Cristazarin is a compound that has important health benefits produced by lichens in the presence of sunlight and keto-sugar fructose. Most of the lichens yield many bioactive components when treated with many other carbohydrates like sucrose. These plants yield many compounds like phenols, polyols, ribitol, and sorbitol (Jeong *et al.*, 2021). The part of the lichen known as thalli is important in yielding usnic acid in high amounts (Boitsova *et al.*, 2020).

Lichens are the species that can grow in Eastern Himalaya, Antarctica, Norway (Phinney *et al.*, 2022;Schroeter *et al.*, 2021). Italy's Ecoregions are the areas that contain a wide variety of lichens almost 50 percent of the region is fully covered with lichens (Martellos *et al.*, 2020). The western Ghats region is the region where moisture content is much higher and paves the way for the production of many lichen species (Sharath & Jabeen, 2021). Some of the lichens that grow in the dried regions where water content is lower cause lichen to lose its moisture content and it became metabolically inactive and cannot undergo photosynthesis have the potential to combat the dryness because they do not have vascular systems that's why these can tolerate the condition of less supply of water (Ten Veldhuis *et al.*, 2020). Northern regions are also very dense in lichen production (Phinney *et al.*, 2022).

2. Classification of lichens

Lichens contain Chlorophyta (green algae), cyanobacteria (blue algae) and Ascomycetes or Basidiomycetes (fungi). Lichens core and color spectrum is broader. They can be green, yellow, red, orange, grey, black, silver, brown and many other colors. They have bright and dark shades depending on the environmental conditions as when they grow on sunny area their color is usually bright so they can prevent themselves from ultraviolet rays of sun due to which the color of lichen become pale and lichen become dry and brittle while lichens possess dark color in cooler area for better absorption of heat (Dwi Irnawati and Roziaty, 2023). The algae provide food to the fungi for its survival, and the fungal species provide shelter and help the algae to absorb water and other micronutrients. Algae is a photobiont secrete sugar and alcohol molecules that are named as polyols to attract the fungi termed as mycobionts (Pichler *et al.,* 2023) The lichens may live on dry surfaces, may be in moist conditions, and may survive in situations where both conditions are possible (Tina- Picaza and Picaza, 2023). Lichen acts as a cornerstone for mineral cycling, maintains climatic changes in the forest (as they become dormant in hot environment and get its moisture again when the environment changes from hot to cool or in case of rain but cannot survive in severe global warming) and provides shelter and nutrients to the host (Tina- Picaza and Picaza, 2023). Lichen is usually involved in the detection of environmental disturbance, serving as a bio indicator of air pollution, forest life, health, and climate change (Stelate *et al.*, 2022).

Lichens are classified into three major classes based on their growth crustose (crust-like and closely linked to the substratum), foliose (leaf-like and slightly joined to the substratum), and fruticose (shrubs like hanging or erect growing on the substratum). Lichens are divided based on their substrate and are corticolous (bark inhabiting), saxicolous (rock inhabiting), terricolous (soil inhabiting), lichenicolous (lichen inhabiting), muscicolous (moss inhabiting), *etc* (K.P and F.T.Z, 2021).

Lichens can grow in conditions where radiation is extremely high and show protective properties against the ultraviolet rays of the sun (Nguyen *et al.*, 2021). Lichens are involved in the regulation of ecosystems (Vaez and Javad Davarpanah, 2021). They are very important for describing the heterogeneity in living organisms and also interact with the variations that are caused by the changes in the physical composition or the genetic makeup of proteins (Stelate *et al.*, 2022). Lichens grow widely and most abundantly in an environment of humidity, clean wind or good quality, abundant sunshine, and a smooth stratum (Tina- Picaza and Picaza, 2023).

Lichens are more evident in the assessment of pollutants found in the atmosphere and are exposed to environmental changes to identify the rate of pollution (Ndlovu *et al.*, 2019). Aluminum, arsenic, nickel, lead, chromium, cadmium, zinc, and copper are the potentially toxic elements that cause adverse effects in the atmosphere and the lichens are essential for the absorbance of these toxic compounds from the atmosphere (Chahloul *et al.*, 2022). The main feature of the lichen is that these are spread over 8 percent part of the entire land (Dwarakanath *et al.*, 2022). Some lichens can disseminate like they grow on the surface of the other plants and some of them require a specific place on the land surface to show their presence or absence (Benitez *et al.*, 2021). Lichens that are present in areas of high fog content adheres to the host trees or plants and have filaments in their structure to help them move around (Wang et al., 2021b)

Medicinal properties of species from the Parmotrema genus

Lichen is a complex network made by the mutual association of a host fungal, a photobiont partner and an unknown number of other organisms. Lichens can grow under different conditions in nature and can grow in laboratories and the resultant species are considered as the symbiotic phenotype of fungus used to form lichen. Lichens are classified as fungi because they are formed by symbiotic relation and have fungal lifestyle and the fungi responsible for the formation of lichens are integrated under fungi as a whole. Different species of lichens are described in Table 1.

Table 1
The most common species of the *Parmotrema* genus, with their main phenolic compounds, respective medicinal properties, and references.

Scientific name	Bioactive compounds	Properties	Reference
P. austrosinense	Lecanoric acid, polyphenols, steroids, usnic acid	Treat cancer, inhibit microbial growth	(Rajendran *et al.,* 2020)
P. crinitum	Salazinic and stictic acid	Reduce oxidative stress, antimicrobial	(Chakarwarti *et al.*, 2024)
P. hababianum	Depsidone	Anti-diabetic	(Duong *et al.*, 2020)
P. melanothrix	Flavones, alkaloids, and tannin-like phenolic compounds such as atranorin and usnic acid	Reduce free radicals-induced stress	(Satyannarayana *et al.*, 2022)
P. praesorediosum	Polyphenols, Usenamin A, Praesalide E	Prevent from cancer	(Chi *et al.*, 2021)
P. neilgherrense	Polyphenols	Treat viral conditions	(Chakarwarti *et al.*, 2024)
P. reticulatum	Salazinic acid, betulinic acid, gyrphoric acid, consalazinic acid, atranorin, zeorin, leucotylin, lupeol, terpenoid, chloroatranorin and dihydroreynosin	Regulates normal blood glucose level	(Duong *et al.*, 2022)
P. pseudotinctorum	Fructose, glucose and sucrose	Antimicrobial and antibacterial	(Kosanić and Rankovic, 2019)
P. stuppeum	Rather than bioactive compounds methanolic extract of this lichen is used to form silver nanoparticles which possess antibacterial activity	Potential against bacteria and fungi	(Prabhu *et al.*, 2019)
P. saccatilobum	Atranorin	Treat viral infections, cancer and kill microbes	(Baczewska *et al.*, 2024)
P. tinctorum	Flavones, phenols, saponin, and glycosides	Exhibit bactericidal and fungicidal activity	(Shiromi *et al.*, 2021)

3. Nutritional value

Lichen has primary metabolites like carbohydrates (α- and β-glucan and galactomannan) mainly polysaccharides, protein, vitamins (C, A, E, D, B1, B2, B3, B5, B7, B9, B12), minerals like calcium, potassium, magnesium, phosphorus, iron, zinc, oxalic acid, linoleic, and linolenic acid, and coloring agents that are chlorophyll and carotenoids (Furmanek *et al.*, 2022).

3.1. *Carbohydrates*

A class of carbohydrates, Polysaccharides (53 g/100g**)**, are essential for the maintenance of gastrointestinal tract health and promote the growth of beneficial bacteria in the gastrointestinal tract. These help lower the risk of hyperglycemia and heart problems, improve immunity, and reduce high body weight (Liu *et al.*, 2021).

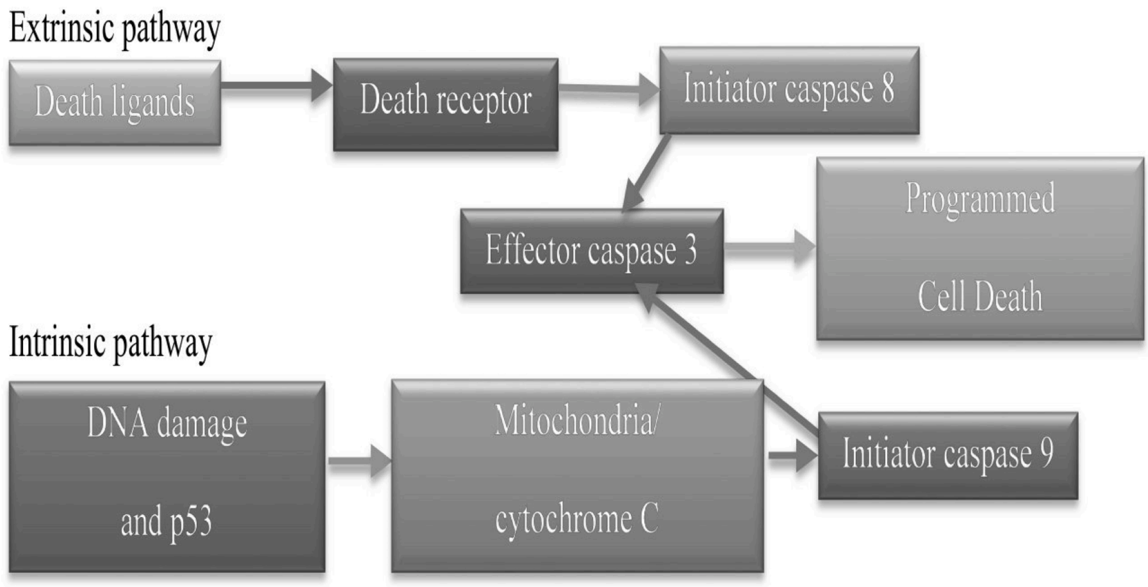

Figure 1. Role of B7 in cell-death pathway.

3.2. Protein

Essential for reducing the risk of heart problems, insulin resistance, and increased body weight (Päivärinta *et al.*, 2020). Proteins (6 g/100g) are compounds made up of amino acids. These amino acids may be essential and non-essential which can be made by the body and can also be obtained from the diet as well (Mihaylova *et al.*, 2021).

3.3. Vitamins

The lichen (*Parmotrema perlatum*) contains certain vitamins including vitamins A (260mcg/100g), D, E, C (21mg/100g), B1, B2, B3, B5, B7, B9, and B12. Vitamin A is dissolved in fat and helps the growth and improve the vision, and functionality of different organ systems, boosts immunity, maintains genetic sequence, lowers the risk of inflammation, combats free radicals, and helps in the oxidation of fat (Huang *et al.*, 2023). Vitamin B1, also known as thiamin is involved in the treatment of mental health problems like Alzheimer's disease, enhances cognition and prevents memory loss in older age (Ji *et al.*, 2024). Vitamin B2 is necessary for the maintenance of biochemical processes in the body and helps to reduce inflammation as well as oxidative stress in the body. Vitamin B3 helps in the regulation of metabolic functions and treats diseases caused by disturbances in metabolic function like increased body weight, hyperglycemia, gastritis, etc. (Wu *et al.*, 2020). Vitamin B5 is usually dissolved in water the other name used for this is pantothenic acid involved in treating degenerative disease, regulating glucose metabolism, lowering the proliferation of cells, improving metabolism, improving cognition, lowering high blood pressure, and increasing the defense system of the body (Xu *et al.*, 2020). Vitamin B7 is produced in the body with the help of healthy bacteria present in the intestine, and when this essential nutrient cannot be produced, it is consumed from a diet rich in pre and probiotics, which can promote the growth of healthy bacteria. It is used to treat inflamed tissues, mental problems, and cell death and to regulate reactions in the body (Reininghaus *et al.*, 2020). Two cell lines like A2780 and HT-29 taken and treated with four types of lichens bioactive compounds like usnic acid, parietin, gyrophoric acid and atranorin to access their effect in cell death. Out of them two compounds usnic acid and atranorin show positive effect in apoptotic pathway in mitochondria and induce massive loss of membrane of mitochondria by activating the caspase 3. Usnic acid and atranorin reduce mitochondrial membrane potential in human carcinoma in HT-29 & A2780 cancer cells. They reduce the production of reactive oxygen species (ROS) and reactive nitrogen species (RNS) by effecting the mitochondrial membrane potential because both ROS & RNS interfere with apoptosis. Usnic acid involves in the stabilization or activity of p53 protein that has no direct effect on cell death signaling but can influence overall outcome. In HT-29 cell line usnic acid and atranorin cleave the polymerase and effective in activating the initiator caspase 8,9 and 3 which ultimately leads towards programmed cell death caused by the fragmentation of DNA (Bačkorová et al., 2012). Figure 1: Explain the cell death pathways.

Vitamin B9 helps to maintain blood sugar levels and prevent nerve damage. It is mandatory for the betterment of individuals with diseases associated with metabolic reactions. Vitamin B12 helps to regulate blood sugar levels, helps in the digestion and absorption of carbs, and can be produced in the body. In older age, vitamin B12 activity decreases and causes many health issues (Satapathy *et al.*, 2020).

Vitamin D is essential for the maintenance of healthy bones by the pathway of enhancing the mineral count of the bones to promote strong bones and improve calcium absorption to help in the treatment of porous bones and bend bones in children (LeBoff *et al.*, 2020). Vitamin D helps to improve the condition of hypertension, heart problems, mental issues, and muscle strength and supports immune function (Bischoff-Ferrari *et al.*, 2021). Vitamin E is a naturally occurring nutrient that protect against reactive oxygen species and helps to lower the risk of cell death and prevent the oxidation of fat (Hu *et al.*, 2021). Vitamin C helps in the absorption of iron, strengthens the blood vessels, lowers free radicals, and treats heart problems and hypertension (Ren *et al.*, 2022).

3.4. Minerals

Minerals found in *P. perlatum* lichen are calcium, potassium, magnesium, phosphorus, iron, zinc, and oxalic acid. Calcium (180 mg/100g) is an essential mineral that is involved in vitamin D absorption, improving bone health, increasing the storage of minerals in bones, reducing the risk of fracturing bones, and maintaining muscle health (Malczewska-Lenczowska *et al.*, 2024). Probiotics present in the diet are also crucial for the absorption of calcium and bone health (Yu *et al.*, 2024).

Potassium is linked with the potential effect of reducing the risk of cardiovascular diseases, high blood pressure, and chronic kidney disease (Turban *et al.*, 2021). Magnesium helps in the enhancement of enzymes

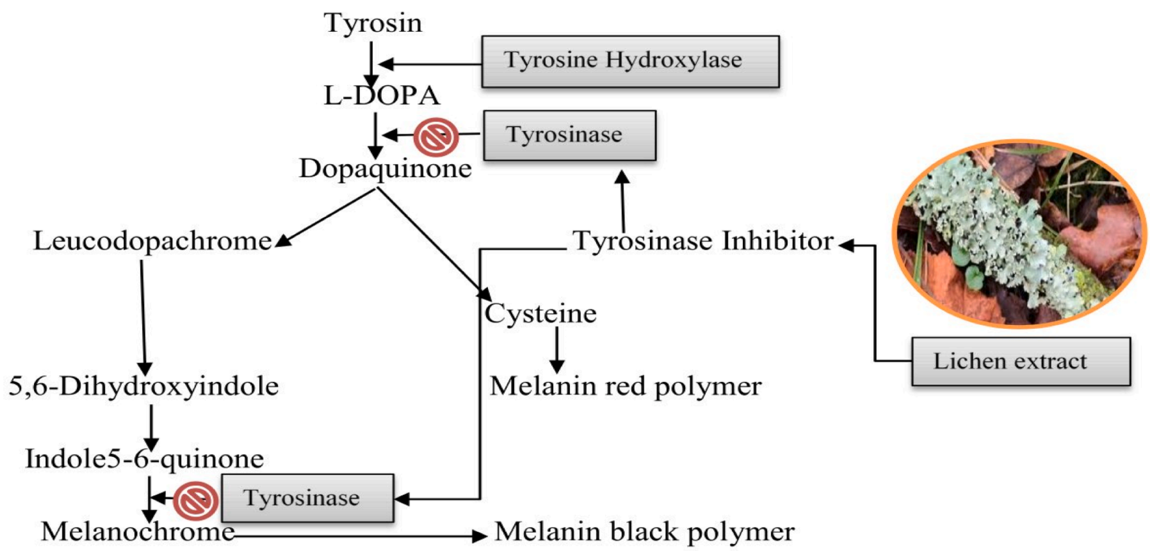

Figure 2. Lichen extract hinders the production of melanin.

involved in the conversion of vitamin D into its active form vitamin D3 and metabolizes it, improves the immune system, and protects the body from the attack of viruses (Tan *et al.*, 2020). Phosphorus is the most abundant mineral found in nature that can be used in many body processes and maintains normal pH levels in the body, maintaining the level of energy, transfer of information, membrane bilayer synthesis, and the management of certain diseases (Volk *et al.*, 2022). Dicalcium phosphate is the best alternative to phosphorus, as it improves immune health, growth, and reproductive health (Sana *et al.*, 2024).

Iron (13.5 mg/100g) is essential for the formation of bone cells, collagen protein, and conversion of vitamin D in its most activated form D3, and is involved in the absorption of vitamin C (Malczewska-Lenczowska *et al.*, 2024). Zinc is the mineral essential for most of the enzymes to do their work, for protein synthesis and messenger RNA formation, transfer signals, maintaining balance in the body, treating diarrhea, immunity boosting, kidney disease, cancer, development, metabolic processes, and for the development of cognition (Tokuyama *et al.*, 2021). Oxalic acid is a natural compound that is essential for killing the viruses and fungal microorganisms entering the body with the help of the immune system, reducing oxidative stress, and also taking part in the maintenance of many other functions of the body (GarcíaPastor *et al.*, 2020). According to the WHO, in 2013 there was a major risk of microbial infections. 9.2 million people were affected by microbes. Lichens have various substances that are favorable for the treatment of infection due to their potential against bacteria and microbes (Rahid *et al.*, 2024).

3.5. Linoleic and linolenic acids

These are polyunsaturated fatty acids involved in nerve maintenance, treating mental problems, transferring information into cells, and also playing a pivotal role in the synthesis of messenger RNA (Dec *et al.*, 2023).

3.6. Coloring agents (chlorophyll and carotenoids)

Both of these are crucial for giving the color of fruits and vegetables their green, orange, yellow, and red color. These are also helpful in many pathways in the body. Carotenoids are the form of vitamin A that helps in the maintenance of proper vision while chlorophyll is important to resynthesize different cells and protect the largest organ of the body from infectious diseases (Turkiewicz *et al.*, 2020).

4. Medicinal uses and health benefits

Lichens are rich in antioxidant compounds that help reduce oxidative stress (when the concentration of free radicals becomes higher than the antioxidant in the body the condition is called oxidative stress) by electron transfer in free radicals, maintain internal antioxidant system work as metal chelates in living organisms and reduce the rate of neurodegenerative disease like Alzheimer's disease (Radhakrishnan *et al.*, 2024). Natural antioxidants are more beneficial than synthetic ones because of their toxicity and harmful effects. Nowadays, natural antioxidant gain more importance in the pharmaceutical, chemical, and food industries (Ureña-Vacas *et al.*, 2022).

Lichens have anti-diabetic effect (Tartouga *et al.*, 2022). In diabetes the beta cells of the pancreas produce insulin, but our body cells are unable to respond to this insulin. Due to insulin resistance, the level of glucose exceeds in the body this condition is called hyperglycemia (Kurek *et al.*, 2020). *P. perlatum* works as an antibacterial agent (Devi *et al.*, 2021). Lichen is used to inhibit the activity of different bacteria like *Salmonella typhi* which is the bacteria responsible for the occurrence of typhoid in humans. This is the major cause of many digestive problems, gastric issues, and unconsciousness when lasts for more than 7 days (Maulidiyah *et al.*, 2020).

Lichen shows antifungal activity. *Aspergillus spp.* is a fungus that affects the production and storage of food, reduces food safety and increases the chance of contamination that leads to health problems. The secondary metabolites of lichens have a remedial role in the form of agents (fungicides) that control plant diseases by acting as preservatives (Furmanek *et al.*, 2022). The secondary metabolite usnic acid found in the genus *Parmelia* has calcium-blocking activities. It is useful in the dilation of arteries, which are becoming narrow due to the calcium and potassium. Due to the dilation properties of the active compounds of *P. perlatum,* it is essential for the treatment of high blood pressure, diarrhea, and inflammation of the bronchi (Hussain *et al.*, 2021).

Cancer is a condition in the body that occurs when the cells of the body grow abnormally. It paves the way for many other diseases. If the cells of the bones, cartilage, and muscles start to proliferate at first then the condition is known as sarcoma and when the proliferative cells move toward the other organs it is known as a metastatic condition (Lira et al., 2023). The lichen species protects from cancer of the skin cells, prosthetic glands, and cancer of the lining of different organs (Aoussar *et al.*, 2020). The *P. perlatum* contains metabolites like proto-lichestric acid that are essential for the treatment of neurodegenerative diseases like Alzheimer's disease and dementia by the mechanism of inactivation of

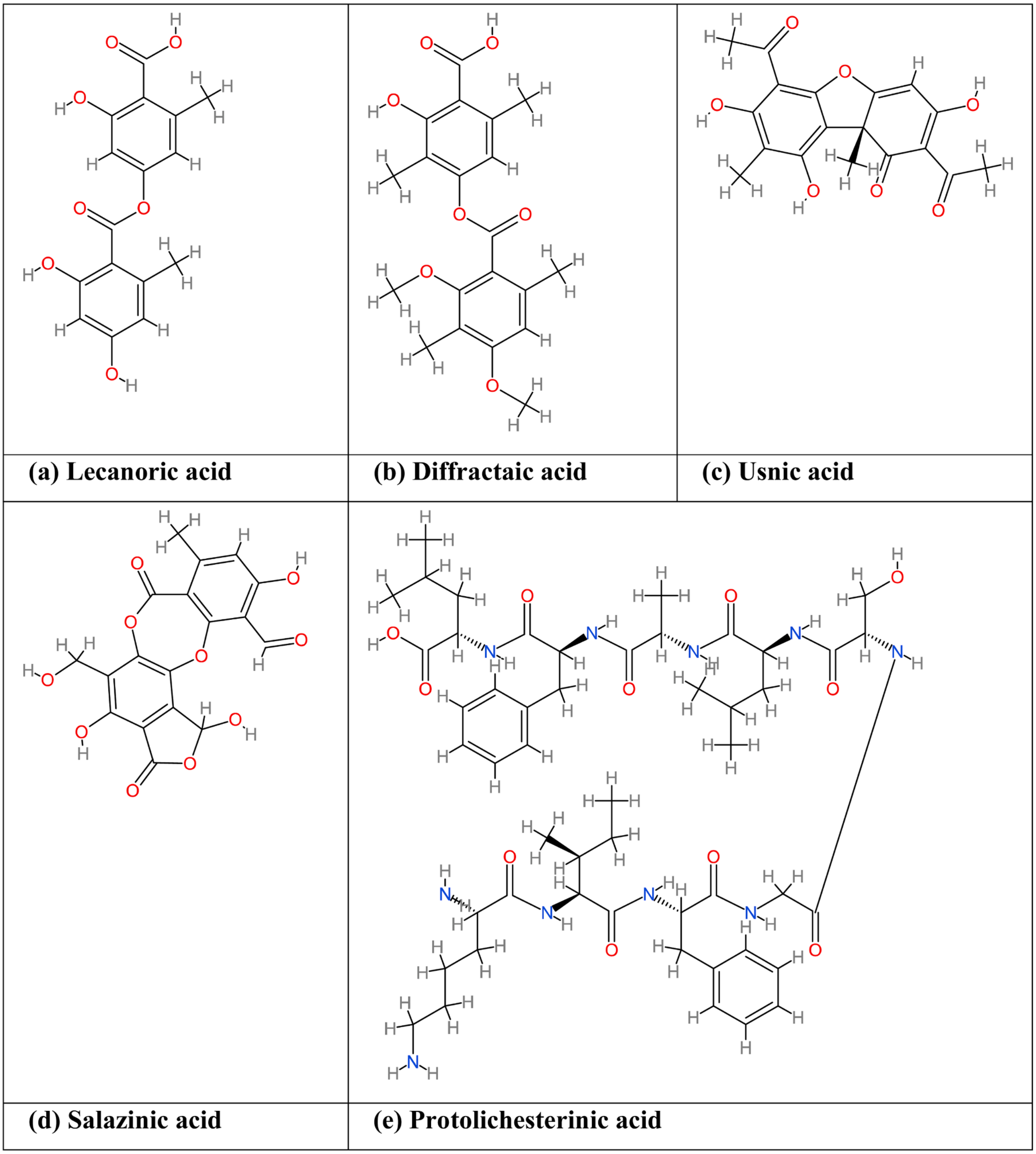

Figure 3. Chemical structures of acids found in *P. perlatum.*

the cholinesterase inhibitors that reduce the action of acetylcholine (Ureña-Vacas *et al.*, 2022). Saponins present in the lichen extract are useful in the treatment of kidney problems by activating the pathway of nuclear factor erythroid 2-related factor 2 (Nrf2) (Mi *et al.*, 2022). while other compounds like triterpene are essential for lowering the level of uric acid and ultimately lowering the risk of renal disorders (Hlophe *et al.*, 2020).

Skin is the largest organ of the body that provides insulation against diseases or injuries and maintains the homeostasis of the body. The lichen *P. perlatum* has the potential to increase the body's defense system against pathogens and other microorganisms to improve the wound's healing capacity (Wang *et al.*, 2021a). Melanin is found in the skin to protect it from sun rays. Alteration in the production of melanin causes certain skin problems like hyperpigmentation. Lichens play a dynamic role in the inhibition of enzymes phenolase essential for melanin synthesis just like tyrosinase. *P. perlatum, Letharia vulpina, Cetraria. islandica* and *Flavoparmelia caperata* extract is used to inhibit tyrosinase activity in zebrafish extracts. Embryos were collected and treated with the extract along with *L. vulpina* methanol extract and *C. islandica* chloroform-methanol extract. Arbutin (8Mm) is used in positive control and reduces melanin synthesis to about 50% while the methanol extract of *L. vulpina* is reduced at 10μg/mL, and *C. islandica* chloroform-methanol extract lowers the melanin synthesis at a concentration of 50μg/mL. Tyrosinase inhibition activity was also observed in the four lichen extracts in a cell-free assay and observed that the most inhibitory effect was seen by *L. vulpina* and *C. islandica* extract that provide evidence for future use of these two lichen extracts in cosmetic products for the purpose of skin whitening (Malaspina *et al.*,2020). Figure 2 explains the effect of lichen extract to inhibit the excess production of melanin.

Staphylococcus aureus is a form of bacteria that causes several skin infections, lung infections and excessive activation of the immune system and can be treated by lichen extract (Shiromi *et al.*, 2021). Tuberculosis is an infection of the lungs caused by the bacteria *Mycobacterium* *tuberculosis*. The phytochemicals present in the lichens *P. perlatum* can inhibit the activity and growth of the bacteria that cause tuberculosis (Pant *et al.*, 2021).

Lecanoric acid is the component of *Umbilicaria decussata* extract that in general possess anti-coagulation effect and is best suited for reducing the risk of blood clotting and preventing diseases like plaque formation in the arteries and other cardiovascular diseases (Vaez and Javad Davarpanah, 2021). Secondary metabolites of lichens are also used in the treatment of inflammation especially inflammation of joints and other parts of the body or in response to any disease or injury, which is the response to immune reactions (Ytterberg *et al.*, 2022). Inflammation is a sign of the body for the curing disease and shows the urge for treatment (Mendili *et al.*, 2022).

P. perlatum contains most of the bioactive compounds like polyphenols which are essential for the regulation of melanin and protect the skin from the adverse effects of higher levels of melanin which is the substance that is used for the protection of the largest insulating organ of the body from the effect of sun rays (Malaspina *et al.*, 2020). Respiratory syncytial viral infection is a condition caused by the attack of viruses in the body and leads to death in older people, adults, and especially children of age 5 years. *P. perlatum* contains components to treat or kill the viruses entering the body by boosting the body's natural defense system (Diveikina *et al.*, 2023).

5. Chemical structures

P. perlatum contains several acidic compounds that perform specific functions in the body and play key roles in different mechanisms of the body. They have specific structures as shown in Figure 3.

6. Bioactive compounds and biological activities

Lichens are considered as the abundant source of secondary metabolites and bioactive compounds that make them suitable for their applications in the medicinal and biotechnological fields. Major techniques that are used for studying them includes high resolution chromatography technique (HPLC) and mass spectrometry (MS) (Prado *et al.*, 2025). *P. perlatum* contains secondary metabolites that are tannin, saponins, alkaloids terpenoids, flavonoids, steroids, phosphates, and sulfates which are bitter and essential for the growth of microorganisms. Therefore, most of the herbs are considered medicinal herbs as they act as anti-infective agent in the treatment of infection (Devi *et al.*, 2021). The polysaccharides present in lichen show anticancer activity. Lichens have polyphenols that affect the concentration of secondary metabolites which are atranorin or usnic acid (Furmanek *et al.*, 2022).

Flavonoids are bioactive compounds that are produced by most plants and lichens. These are the fastest species found in plant origin and are formed in the specific part of plants known as cytosol by the aid of different enzymes throughout the phenyl-propanoid pathways. These can inhibit microbial attack and protect plants from climate change (Hijaz *et al.*, 2020). Flavonoids are the most appreciable kind of phytochemicals that can be used in different products and medicines and can be involved in the treatment of various disorders like Alzheimer's disease, cell proliferation, and plaque formation in the arteries (Pandey *et al.*, 2021). Terpenoids are compounds that are involved in many biological processes and provide protection to plants from natural disasters (He *et al.*, 2023). Saponins are bitter and have anti-insect, anti-proliferative, anti-fungal, antioxidant, and bacteriostatic properties (Singh and Singh, 2020). Saponins are essential for changing the composition of the gut microbiome and for the metabolism in the liver and kidney also related to intestinal problems (Zhang *et al.*, 2022). Atranorin is the form of secondary metabolite in the lichen and acts as a bioactive compound as it shows a positive response against the defense from bacteria, fungi, inflammation, viruses, pain, and immune modulation (Simko *et al.*, 2022).

Table 2
Region of some specific forms of lichens from genus *Parmotrema*.

Lichen	Region	Reference
P. austrosinense	Hilly Areas, New Zeeland & Island	(Rajendran *et al.*, 2020)
P. crinitum	Tasmania, Asia, Ireland & India	(Kantvilas, 2023)
P. hababianum	Hills of Tamil in India	(Chakarwarti *et al.*, 2024)
P. melanothrix	Deserts of South Africa and Namibia	(Ytterberg *et al.*, 2022)
P. praesorediosum	Vietnam	(Chi *et al.*, 2021)
P. neilgherrense	Tamil India	(Chakarwarti *et al.*, 2024)
P. reticulatum	Australia, Vietnam & Island	(Duong *et al.*, 2022)
P. pseudotinctorum	Spain	(Chiva *et al.*, 2023)
P. stuppeum	India	(Prabhu *et al.*, 2019)
P. saccatilobum	Himalayan region of India	(Thakur *et al.*, 2019)
P. tinctorum	India	(Kosanić and Rankovic, 2019)

Lecanoric acid is a bioactive compound that shows potential against inflammation and the attack of microbes (Shiromi *et al.*, 2021). It is used in the industry for dyeing purposes and gives a purple color (Kusmoro *et al.*, 2018). Orcin is a type of phenol and phenolic glycoside present in the *P. perlatum* lichen that possesses properties for the treatment of bone porosity, depression before the pre-menopausal period, and anxiety (Liu *et al.*, 2023). Erythrolein found in the *P. perlatum* species of lichens is the most important bioactive compound essential for anemia in patients with chronic kidney disease. It is also helpful for improving energy levels and physiological functions of the body (Wang *et al.*, 2021). Azolitmin is a compound used as a litmus to give color. It has a blue color when it is treated with alkaline material and is found in the *Parmeliaceae* family of lichens. It is soluble in water and is present in brown-red color. Spaniolitmin is the other compound in the lichen which is used as litmus and has a bright red color. It is not dissolved in alcohol but slightly dissolved in water and gives a red color (Wisniak, 2019). Tannins are phenolic compounds characterized by astringency and a molecular mass ranging from 300 to 3000. Tannins have a defense against pathogens and give other health benefits like protection from the attack of reactive oxygen species, lowering the proliferation of cells, reducing inflammation, and combat the risks of high body weight and high levels of glucose (Palacios *et al.*, 2021).

Glycosides are a group of flavonoids that are classified into quercetins and luteolins and possess antioxidant properties (Asplund *et al.*, 2021). Oligo dynamic Elements are the compounds such as zinc and copper present in the lichens that have different functions in the body. They are essential for the treatment of bone disorders or infections caused by bone transplantation or after bone surgery. These elements have protective properties against certain microbes and bacteria (Segura-Pérez *et al.*, 2020). Steroidal Aglycone is the molecule that is separated from oligosaccharides by the process of hydrolysis and considered as non-sugar molecule found in lichens and possess anti-tumor and antiviral properties (Asplund *et al.*, 2021). Usnic Acid is the most abundant secondary metabolite found in lichen *P. perlatum* which has anti-bacterial properties. It is commonly used in pharmacies for the development of medicines and is used in cosmetic products. Recently the substitutes of usnic acid are proven to have anti-microbial properties (Shiromi *et al.*, 2021). It is bitter in taste, yellow in color, and solid in nature (Wu *et al.*, 2022). Usnic acid shows the defense against the entry of algae, protozoa, viruses, fungi, mycobacterium, and gram-positive bacteria (Malakhova *et al.*, 2023). Diffractaic acid is found in most of the lichen species as a secondary metabolite and belongs to the family of depsides. It has a positive effect in the treatment of viral and bacterial infections, ulcer treatment, killing insects, and providing protection to the liver cells (Diveikina *et al.*, 2023). Atranorin is a compound that is used for coloring purposes. It gives a yellow color during fermentation (Kusmoro *et al.*, 2018).

Salazinic acid is the depsidone molecule that is mostly found in lichens and reduces the level of free radicals in the body and inhibits the activity of alpha-glucosidase in the body to protect from the elevated

Table 3
Therapeutic effect of lichen's bioactive compounds.

Compound	Effect	Study Design	Duration	Mechanism	Results/Health Effect	Citation
Usnic acid	Anti-bacterial	*In vitro*	3-24 hr	The antibacterial properties of usnic acid were determined by using the paper disc diffusion method	Usnic acid mimics the propagation of *E. coli, S. aureus*, & *S. typhi* bacteria at 500 & 1000 mg/mL concentrations with 12, 17 & 14 mM inhibition zones respectively	(Maulidiyah *et al.*, 2020)
Usnic acid	Anti-inflammatory	*In vivo*	10 days	Mice separated into 2 groups 0 days, treated with vehicle and usnic acid (5 or 25 mg/kg) 20 mg/kg MPTP was induced for Parkinson's disease pathologies	Usnic acid inhibits the activation of NF-KB and glial activation by MPP+ or is useful for neurodegenerative problems	(Lee *et al.*, 2020)
Tdp1	Anti-tumor	*In vivo* (5 groups of female mice)	25 days	7 female mice in each group are treated with different doses of olaparib and OL7-43. It was injected into the mice with 0.2 mL on day 13 of tumor grafting and the weight of the mice was checked frequently	Tdp1 inhibitor OL7-43 increased the antitumor effect and anti-metastatic effect in Lewis and Krebs 2 carcinoma model	(Kornienko *et al.*, 2023)
Diffractaic acid	Anti-bacterial	*In vitro*	24 hr	Diffractaic acid is tested by using dilution techniques. Positive control was treated with chloramphenicol & amoxicillin at 1000 ppm, and negative control was treated with distilled water & acetone. The semisolid NA is poured into petri plates & incubated at 37°C for 24 hr	Diffractaic acid has strong anti-bacterial power and inhibits the propagation of *Staphylococcus aureus* and *E. coli* bacteria at 750-1000 ppm of concentration	(Maulidiyah *et al.*, 2021)
Salazinic acid	Anti-necrosis	*In vivo* (Male Swiss albino mice 35-45g of 2 months)	7 days	Mice with solid tumors are treated with salazinic acid 25-50 mg/kg and 5 fluorouracil 20 mg/kg after 24 hr of inoculation period	Salazinic acid has more potential in the prevention of steatosis and tissue necrosis	(Lira et al., 2023)
Atranorin	Anti-piroplasmic activity	*In vitro*	45-60 days	Both *in vivo* and *in vitro* experiments are being done to identify the anti-piroplasmic effect of atranorin alone or in combination with other drugs like DA, AV & CF	The atranorin is very effective to treat clinical diseases in humans & animals	(Beshbishy *et al.*, 2020)
Atranorin	Anti-piroplasmic activity	*In vivo*	45-60 days	The chemotherapeutic effect is checked with a combination of drugs on 6 species of Parasites while *in vivo* experiment showed that atranorin prohibits *B. microti* proliferation in mice up to 68.17%	Atranorin has proved to be efficient in chemotherapeutic activities	
Atranorin	Anti-depressive	*In vivo* (Male Wister rats)	30 days	The male progeny was divided into three groups control group, a second depression-like group, and third atranorin a restricted group treated with 10 mg/kg of atranorin for one month	Atranorin is the most abundant secondary metabolite in lichens increases the process of neurogenesis & treats depression	(Urbanska *et al.*, 2022)
Saponin	Anti-diabetic	*In silico* and *in vitro*		Both *in vitro* and *in silico* experiments are used to determine the enzyme-inhibited activities of steroidal saponins derived from *T. govanianum.* These saponins show alpha-amylase, alpha-glucosidase, and DPP-IV inhibitory potential	The extracts of saponins have characteristics to manage the blood glucose level and make it essential for the treatment of diabetes	(Suresh *et al.*, 2021)
Saponins	Anti-hypercholesterolemic	*In vitro*	24-hr	Japanese starfish extract is collected for the experiment. Divided into seven specimens and kept at a temperature range of 30°C. The cholesterol binding ability is determined by the use of FeCl3 and H_2SO_4 method. The mixture is incubated at 37°C for 1 hr and the cholesterol saponin is obtained by using centrifugation for 15 minutes at 350 g	*A. amurensis* extract out of seven specimens has the saponin-cholesterol binding ability which makes it useful for lowering cholesterol levels in the body & encourages the use of saponin in food & drugs	(Sharmin *et al.*, 2021)
Lecanoric acid	Anti-Proliferative	*In vitro*	8 days	Different types of cells like HCT-116, HEK293T, Hela, NIH3T3, RAW246 & PBMCs are treated with 0, 0.3, 3, 30 µg/mL of evernic, lecanorin, atranorin, and vehicle and incubated at a temperature of 37°C for 24 hr	It is observed that cell lines responsive to lecanoric acid show anti-proliferative and anti-cancer potential without causing any harmful effect on immune cells	(Roser *et al.*, 2022)
Flavonoids	Anti-hemorrhagic	*In vivo* (199 Hemorrhoidal Disease Patients)	42 days	The conservative and treatment group and treated with flavonoids and Centella. The time to stop blood flow is 3-4 weeks in patients treated with flavonoids and Centella and 5 weeks in patients who get routine treatment	Flavonoids are beneficial for bleeding and to treat anal irritation in patients with HD	(Chiaretti *et al.*, 2020)

(*continued on next page*)

Table 3 (*continued*)

Compound	Effect	Study Design	Duration	Mechanism	Results/Health Effect	Citation
Usnic acid	Anti-angiogenic	*In vitro*	72 hr	Primary Human Umbilical Cord Vein Endothelial Cells were collected and treated with a buffer solution of NaCl, pencilin, etc. The cells are incubated at 37°C temperature for 20 minutes. Then the cells were centrifuged at 1000 rpm for 5 minutes. After that, the HUVEC cells were re-suspended and treated with the medium again at different concentrations	Usnic acid contains antiangiogenic properties and mimics the VEGF & bFGF and induced angiogenicity determined by both *in vitro* and *ex ovo* experiments	(Petrová *et al.*, 2022)
Triterpene	Anti-hyperuricemic	*In vivo* (30 rats)	14 days	The anti-hyperurecimic effect of RA3 is investigated by using adenine and gentamicin for the formation of hyperuricemia. Divided into two groups control and model group. The rat in the model group was further divided into five groups in which the experiment group was treated with RA3 50-100 mg/kg body weight daily for 14 days	Triterpene has a potential anti-hyperuricemic effect as well as it can be used for nephroprotection and CVD	(Hlophe *et al.*, 2020)
Glycosides	Anti-diabetic	*In vivo* (70 male rats)	13 weeks	10 kept healthy 60 with diabetes and treated with stevia and metformin and one group kept untreated. The rats were fed a high-fat diet to induce insulin resistance. At the end after 6 hrs of fasting rats are sacrificed and blood is collected and transferred to the lab for further analysis	Glycosides can be used as an alternative therapy to treat type II diabetes mellitus, and further research is needed to investigate its use in clinics at the molecular level	(Kurek *et al.*, 2020)

levels of glucose in the blood. Salazinic acid also acts as the inhibitory agent for tumor progression by the mechanism of suppressing the expression of protein for tumor necrosis factor-alpha (Killari *et al.*, 2023). Tridecyl Myristate is the active compound in the *P. perlatum* species of lichens that is the best antifungal agent (Singh and Singh, 2020). Proto-lichesterinic acid and lichesterinic acid both are coloring pigments that give a green color and are a group of phytohormones (Malakhova *et al.*, 2023). The 3-Ketooleanane metabolite is present in the *Parmelia perlata* lichens which is essential to treat the attack of fungus (Singh and Singh, 2020). Icosan-1-ol is the compound present in lichens and is best suited for the prevention of corrosion in industries (Wazzan, 2023). Labdane-type triterpenoid; named Permelabdone and Lano-2-en-Type Triterpene; named Permelanostene defend against bacterial attack (Singh and Singh, 2020). Table 2 explain the region of occurrence of different lichen species and Table 3 indicate bioactive compounds present in lichen and their role in preventing disease or to improve health. Table 4 includes lichen species that are found all over the world and used in the cure of different ailments.

7. Conclusion

Lichens that usually grows in mountainous regions used in the cure of many health problems and also involved in the formation of medicines and cosmetics. They play an essential role in the dyeing industry for coloring. They are used in different pharmaceutical and cosmetic industries due to the presence of certain nutrients and phenolic compounds. Current studies indicate *in vitro* effectiveness but for *in vivo* examination, pharmacokinetics, dose dependent response, toxicity and evaluation for safety needs further research. Beyond these standards for extraction of lichen extract, use of chemicals and markers for quality control are also important. In future research it is necessary to alleviate these gaps to use lichens for therapeutic purposes most effectively.

Abbreviations

Nrf2 Nuclear factor erythroid 2-related factor 2
E. Coli Escherichia coli
S. Aureus Staphylococcus aureus
MPTP 1-Methyl-4-phenyl-1,2,3,6-tetrahydropyridine
NF-KB Nuclear Factor Kappa B
MPP+ 1-Methyl-4-phenylpyridium
BSA Bovine Serum Albumin
ROS Reactive Oxygen Specie
TNF Tumor Necrosis Factor
OL7-43 Tyrosyl-DNA phosphodiesterase 1 Inhibitor
Tdp1 Tyrosyl-DNA phosphodiesterase 1 pPM Parts per Million
NA Excluding the Agar
NaCl Sodium Chloride
GI Gastro Intestinal
MTT Assay 3-(4,5-dimethylthiazole -2-yl)-2,5diphenyltetrazium bromide
RD Cell Line Derived from Human Rhabdomyosarcoma
Hep2c Cell Line Derived from Human Cervix Carcinoma
Hela Cervical Cancer Cell Line
L2OB Cell Line Derived from Murine Fibroblast nm Nanometer
UV Ultra Violet
UVB Ultra Violet B (280-320nm wavelength)
ATR.AV Atranorin. Atovaquone
ATR.DA Atranorin. Diminazene Aceturate
DA Diminazene Aceturate
AV Atovaquone
CF Clofazimine
B. Microti Babesia microti
T. Govanianum Trillium govanianum
DPP-IV Dipeptidyl Peptidase IV
FeCl3 Ferric Chloride
H2SO4 Sulfuric Acid
HCT-116 Human Colorectal Cancer Cell Lines
HEK293T Human Embryonic Kidney 293 Cell Line
NIH3T3 Mouse Embryonic Fibroblast Cell Line
RAW246 Murine Macrophage Cell Line
PBMCs Primary Peripheral Blood Mononuclear Cells
HD Hemorrhoidal Disease
HUVECs Primary Human Umbilical Cord Vein Endothelial Cells
RPM Revolution per Minute
VEGF Vascular Endothelial Growth Factor bFGF Basic Fibroblast

Table 4
Potential health benefits of *Parmotrema* and some other lichen species.

Compound	Effect	Study design	Duration	Mechanism	Results/health effects	Citation
P. hypotropa	Anti-Inflammatory	*In vitro*	15 minutes/ 24 hr.	Different concentrations of BSA, methanol, and diclofenac sodium are added in tubes and incubated at 37°C for 15 minutes and heated for 5 minutes at 72°C. After cooling the absorbance was measured at 660 nm	*P. hypotropa* can reduce inflammation by inhibiting the denaturing of protein and the production of ROS and TNF alpha by keratinocytes	(Tartouga *et al.*, 2022)
Collema furfuraceum	Anti-microbial	*In vitro*	72 hr	Paper disc diffusion method is used, and overnight prepared culture suspension is poured onto the petri plates. Tetracycline and streptomycin disc is also used as control. The Petri plates are sealed and incubated at a temperature of 37°C for 24 hr. and 28°C for 72 hr. for bacterial and fungal inhibition respectively.	*C. furfuraceum* lichens possess antimicrobial effects against drug-resistant bacteria and fungi	(Khan *et al.*, 2023)
P. perlatum	Antidiarrheal	*In vivo* (Albino mice)	24 hr	5 groups with 6 mice in each group were made. The negative control group was treated with 0.9 % NaCl and the positive (2-5) control group mice were treated with prepared plant extract with different doses of 1,2,4 and 6 g/kg respectively	*P. perlatum* shows effectiveness in the treatment of GI, respiratory, and diarrheal conditions. Further research is necessary to support this investigation	(Hussain *et al.*, 2021)
P. perlata	Cytotoxic	*In vitro*	48 hr	The MTT assay method is used to determine the effect of *P. perlata* on the malignant cells. RD, Hep2c, Hela, and L2OB were selected and treated within well culture plates in a nutrient medium and grew at 37 for 24 hr. The absorbance rate is measured at 580 nm	Lichen *P. perlata* contains secondary metabolites which have anticancer agents	(Manojlović *et al.*, 2021)
P. tinctorum	Photoprotective	*In vitro*	30 minutes	The Ligouin method is used to evaluate the effect of salazinic acid against UV rays. Ethanol dilution is done for the final sample of concentration 20 μg/mL	*P. tinctorum* exhibits the potential to prevent UVB blockers and is used in cosmetics as sunscreen	(Nguyen *et al.*, 2021)
P. perlatum	Depigmentation	*In vitro*	1 week	Powder of the lichen is prepared and for cell viability, the cell is exposed to 96 well plates for the time of 48 hr, and for the melanin, the cell is placed in 24 well plates	Lichens have a depigmenting effect on cultured cells by inhibiting tyrosinase enzyme activity, making it essential for cosmetic & pharmaceutical use	(Malaspina *et al.*, 2020)
P. perlatum	Tyrosinase enzyme inhibition	*In vitro*	20 minutes	Lichen extract, phosphate buffer, and tyrosinase are mixed in amounts of 10μL, 110 μL, and 20 μL, respectively. Incubate the mixture at 37°C for 10 minutes & re-incubate for 10 minutes after adding the 20 μL of L-Dopa & result is measured at 475 nm by using standard (kojic acid)	These lichens show a tyrosinase enzyme inhibition effect	(Tüzün *et al.*, 2024)
Rocella tinctoria	Anti-fungal	*In vivo* (nine groups of *Galleria mellonela* larva of wt. (0.3±0.03g).	120 hr	Three groups are used as control groups. One is treated with *Candida albican* suspension one remains untreated and one is treated with saline solution. Incubate the larvae at 37°C for 120 hr repeat the process three times and note down the results	The lichen extract shows a positive effect on the survival of larvae infected with *C. albican*	(Frezza *et al.*, 2024)
Umbilicaria crustulosa	Edema	*In vivo* (10 weeks old 80 Wistar albino rats weighed 200 to 260 g)	4 hr	Divided into 8 groups and treated with different doses of extract after induction of inflammation. The reduction of edema was most significant in the group treated with a 200mg/kg dose after 2 hr of inflammation induction	The lichen extract & indomethacin work synergistically in lowering the risk of paw edema in rats	(Tomović *et al.*, 2024)
P. nilgherrense	Anti-fungal	*In vitro*	72 hr	96 well plates cultured with dextrose broth are incubated at 27°C for the time of 72 hr. Ketoconazole is used as a positive control.	The lichen extract is more effective against fungi than standard ketoconazole.	(Kumar *et al.*, 2024)
Ramalina farinacea	cytotoxic	*In vitro*	24 hr	Cells were cultured at 96 well plates with 10^4 cells in each plate. With the addition of 5 % CO_2 well plates are incubated at 37°C for 24 hr in moist condition. After that cell is treated with DPBS and DMEM and the signal is measured at a wavelength of 560/590 nm & noted that well fluorescence signal lacks cells.	Usnic acid extracted from *Ramalina* species is evident for treating the cancer induced by the MCF-7 cell line.	(Darmawan et al, 2024)

Growth Factor
RA-3 Lanosteryl Triterpene(RA-3)
CVD Cardio Vascular Disease
HF Diet High Fat Diet
L-Dopa 3,4-Dihydroxyphenylalanine
CO_2 Carbon Dioxide
DPBS Dulbecco's Phosphate Buffered Saline
DMEM Dulbecco's Modified Eagle's Medium
MCF7 Cell Breast Cancer Cell Line

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Declaration of competing interest

The authors declare no conflict of interest.

Data availability

The data will be available upon request.

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