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REVIEW ARTICLE

Lichens Uses: Surprising Uses of Lichens that Improve Human Life

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ABSTRACT

Lichens are rich in nutrients and in biologically active compounds that belong to different chemical classes. The abilities of different members of Lichens have encouraged researchers to investigate further applications of these Lichens in fields other than the food acnd pharmaceutical industries. In this review, some of the unusual current and potential applications of Lichens are described.

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- Alternative sources of medicine

INTRODUCTION

Lichens are composite organisms containing algae (Trebouxia or Trentepohlia), or cyanobacteria (Nostoc), living among filaments of multiple fungal species in a mutualistic relationship. Lichens dominate vegetation types on about 7% of the planet's surface; additionally, they are important components of primary producers in a wide range of substrates and habitats, including some of the most extreme conditions on earth (North and South Pole, desert, even glass surfaces and others). Many lichens (such as Usnea, Hypogymnia, and Parmelia) are very sensitive to environmental disturbances and they can be used to assess air pollution. Unlike simple dehydration in plants and animals, lichens may experience a complete loss of body water in dry periods. Lichens are important in contributing nitrogen to soils either by forming litter, or predation by herbivores, e.g., snails, which then defecate, providing nitrogen to the soils. In deserts and semi-arid areas, lichens are part of extensive, living biological soil crusts, essential for maintaining the soil structure [1]. The morphology of the lichenized thallus is strongly influenced by the phytobiont and its direct contact with the mycobiont. Lichen thalli have been grouped as: (1) Crustose (phytobiont in a distinct layer below an upper mycrobiont cortical layer with no lower cortex); (2) Leprose (groups of phycobiont surrounded by mycobiont); (3) Foliose (leafy; phycobiont in a layer below an upper cortex with a discrete cortex below, separate from the substratum on which it grows; (4) Filamentose (Filamentous; phycobiont surrounded by a sheath of mycobiont); and (5) Fruticose (Shrubby; erect, vertical or trailing; radial in structure, often attached at the base, with the phycobiont in a layer inside the outer cortex) [2]. Lichens represent a well-known symbiotic relationship between algae and fungi which is successfully used in food industry and for preventing or treating different human diseases. Lichens tend to produce secondary metabolites as a defence mechanism to protect themselves against external predators [2]. Lichens colonize some of the most inhospitable habitats on earth. Lichens are known to pioneer different types of hostile environments from extreme temperatures to desiccated colonisations. Very old environments as well as arid and semi-arid regions like cryptogamic soil crusts are also conditions favouring lichen habitat.

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ROLE IN ENVIRONMENTAL POLLUTION

Lichens are a symbiotic relationship between algae and fungi. The fungus provides shelter for the algae and the algae provides food for the fungi. Lichens do not have roots; instead, they receive all their nutrients from the atmosphere. Pollutants can penetrate and affect the community of lichens. Lichens are sensitive to atmospheric pollution such as Nitrogen (N) because they receive all their nutrients and water from wet and dry atmospheric deposition (fall out). Nitrogen deposition can increase the load of nutrients. Too much N can harm and kill the algae's chlorophyll which is used to produce sugars feeding it and the fungi. As far back as 1866, a study was published on epiphytic lichens used as bioindicators [3]. Lichens are the most studied bioindicators of air quality [4]. They have been defined as "permanent control systems" for air pollution assessment [5]. Many physiological parameters are used to evaluate environmental damage to lichens, such as: photosynthesis [6]; chlorophyll content and degradation [7]; decrease of ATP; variations in respiration levels [7]; changes in the level of endogenous auxins; and ethylene production [8]. Furthermore, laboratory exposure to SO_2 causes relevant membrane damage to lichen cells [9]. Also, lichens that are transplanted into areas with intense vehicle traffic show an increase in Chl *a* + *b* concentration that is proportional to increases in emissions.

The accumulation of heavy metals and trace elements in plants depends upon many factors, such as the availability of elements; the characteristics of the plants, such as species, age, state of health, type of reproduction, etc.; and other parameters such as temperature, available moisture, substratum characteristics, etc. [10]. Contaminants deposit on lichens through normal and indirect precipitation. This latter includes mist, dew, dry sedimentation and gaseous absorption [11]. Indirect precipitation occurs in highly stable atmospheric conditions and contains higher nutriment and contaminant concentrations of different orders of size when compared to normal precipitation [12]. Numerous lichen species have also been identified to accumulate airborne metals like Pb, Ni, Cu, Cd, and Zn in their thalli [13]. In general, three mechanisms have been put forward with regard to the absorption of metals in lichens [14]: 1. Intracellular absorption through an exchange process; 2. Intracellular accumulation; and 3. Entrapment of particles that contain metals. Therefore, lichens are also excellent bio-accumulators of elements and trace elements, since the concentrations found in their thalli can be directly correlated with those in the environment [15]. Lichens can also be used as bio-monitors of pollutants by quantifying the amount of trace element(s) accumulated within them over time [16]. Studies from various parts of the world revealed that lichens are being used to monitor for metal deposition both as active and passive monitors [17]. Because of the excess use of chemical fertilizers and pesticides in the agriculture industry, the physical and chemical texture of the soil changes.

All forms of lichens do not show sensitivity towards pollutants such crustose and foliose lichens which are pollution tolerant. Heavy metal is acquired in large amount by these pollution tolerant lichens [18]. In Europe, *Lecanora conizaeoides* Nyl. is recognized as a common pollution tolerant species for carrying out air pollution studies, however, in tropical Asian countries, *Pyxine cocoes* (Sw.) Nyl. is identified to be an effective pollutant accumulator and monitor [19]. In India *Pyxine cocoes* has been utilized for the assessment of accumulation of heavy metals in commercial, industrial and residential areas of Lucknow by using transplant technique [20]. This species also exhibited its ability to accumulate arsenic and fluoride [21] and heavy metals like Al, As, Cu, Fe and Zn [22].

FOOD AND FODDER

The lichens serve as important source of food for invertebrates. There is convincing evidence that, over many centuries, people from many cultures in widespread parts of the world have eaten or drunk lichens or products derived from lichens. However, there is no evidence that lichens have consistently formed a major part of the diet within any society. Some lichens have been seen as delicacies but more often they appear to have been a food of last resort or have been used to eke out other food supplies. There are a long list of many species that have been consumed by humans. For example, in India a *Parmelia* species has been used as a curry and *Lecanora esculenta* has been eaten by inhabitants of the Middle Eastern deserts, with suggestions that this was the biblical manna. Lichens as food have also been used by man during famines. They are rich in polysaccharides, certain enzymes and some vitamins. *Cetraria islandica* (Iceland moss) is taken as food in Sweden, Norway, Scandinavian countries, Iceland etc. *Lecanora esculenta* is used as food in Israel and *Umbilicaria esculenta* in Japan. Species of *Parmelia* are used as curry powder in India. In France the lichens are used in confectionary for making chocolates and pastries.

Cladonia rangiferina (Reindeer moss) is the main food for reindeers (a kind of deer) in polar countries. *Cetraria islandica* is also used as fodder for horses. Species of *Stereocaulon*, *Evernia*, *Parmelia* and *Lecanora* are also used as fodder [23]. A large number of animals for example, mites, caterpillars, termites, snails, slugs etc. feed partly or completely on lichens.

IN INDUSTRY (IN TEXTILE PROCESSING)

Research has been conducted to promote the use of natural dyes in several fields of food, cosmetics and textile industries [24]. Lichen dyes played a significant role in the industrial revolution. Dyeing of textile materials is commercially the most valued application of lichens and lichen dyes had high economic value for many centuries. Lichens were important for dyeing purple and violet colours. Lichens were used for the dyeing of wool and silk in ancient times and probably the most famous are the lichens known collectively as the orchil lichens [25]. Yellowish, brownish, and reddish-brown colours were obtained using simple dyeing method in which lichens were boiled in water together with mordanted and un-mordanted wool [26]. For example: Atranorinis found in *Parmelia* sp. and *Xanthoria parietina* whereas gyrophoric acid in *Ochrolechia tartarea* and *Lasallia pustulata*. Salizinic acid, the derivative of atranorin, is found in *Parmelia saxatilis* and several other *Parmelia* spp. In Scottish Highlands, woollen materials used in tweeds are dyed in yellowish, reddish, and brownish hues by these lichens [25].

On the other hand, orchil and litmus exist in several species of lichen, e.g., *Roccella* and *Lecanora* sp. [27]. Orchil dye was used to dye wool, silk, wood, feathers, marble, and even leather. Litmus is still used as a reagent for Orchil to react to alkalis and acids [28]. The colour of both litmus and orchil are pH-dependent; in acidic conditions the dyestuffs form red cations while in the basic conditions they give bluish violet colours in their anionic forms [27]. Lichens from *Rocella* sp. contain lecanoric acid up to 3-4 % on dry weight basis [27]. Orchil is a complex mixture of several other orceins e.g., β- and γ-aminoorcein, β- and γ-hydroxyorcein and β- and γ-aminoorceimine [25].

COSMETICS AND PERFUME

From 'Baby creams' to deodorants to face and body lotions, extracts of lichen and other botanicals are becoming common additives in personal care products. Lichen-derived products are widespread in the United States and Europe. One estimate counted more than 90 deodorants and perfumes or colognes that explicitly list lichen-derived ingredients [29] and countless other such products that use potentially allergenic plants of the Compositae family. The most commonly extracted product of lichen is usnic acid. Chemically, usnic acid is a dibenzofuran, which is related to the furocoumarins but is rarely photosensitizing [30]. Furthermore, Lichen acid extract from *Evernia prunastri* is used as a fragrance component. For custom extended-series patch testing, a lichen acid mix is available from Chemo technique (Malmo¨, Sweden); it contains usnic acid, atranorin, and everinic acid, all at < 0.1% in petrolatum. Each allergen is also available separately from Chemotechnique, and usnic acid 0.1% in petrolatum is available from Hermal (Reinbeck, Germany). Oakmoss absolute is one of the eight components of fragrance mix I and is also available separately from Chemotechnique and Hermal. On the other hand, *Evernia, Ramalina, Pseudorina* are reported to have perfumed volatile oils. Due to the aromatic substances present in the thallus, the lichens are used in the preparation of various cosmetic articles, perfumery goods, dhoop, hawan samagri, etc. [23].

MINERALS

The involvement of lichens in rock weathering has been discussed since the end of the 19th century. Julien (1883) mentioned the influence of lichens as an organic agent in the deterioration for stone material [31]. The lichens weathering on mineral surfaces involves both physical and chemical processes. Of these, the physical mechanism is mainly characterized by hyphae penetration and thallus expansion and contraction, whilst for the chemical action oxalic acid and several other lichens substances are important. Many of these secondary metabolic products are powerful metal complexing agents leading to a disintegration of the rock surface [32].

Lichens living on carbonate or silicate rocks, in which calcium oxalates were found, can be both epilithic and endolithic. According to the structure of the thallus, they are mainly crustose, but foliose species are also found. Usually, authors make a conclusion about the release of oxalic acid by the mycobiont of lichens according to the presence of oxalates in their thalli [33]. Crystalline salts of oxalic acid, in particular calcium oxalate monohydrate (whewellite, $Ca(C_2O_4)\ H_2O$) and calcium oxalate dihydrate (weddellite, $Ca(C_2O_4)\ (2.5{-}x)\ H_2O$), are the most common mineral phases forming in the presence of lichens. *Lecanora esculenta* is found in limestone deserts and yields large amount of calcium oxalate crystals. These are 60% of its dry weight [23].

BREWING, DISTILLING AND ESSENTIAL OIL OF LICHENS

Some species of lichen, for example *Cetraria islandica*, contain carbohydrates in the form of lichens. In Sweden and Russia alcohol is produced from these lichens. These lichens are also used in confectionary [23]. The essential oil is the product obtained from a vegetable raw material, either by steam distillation or by mechanical processes from the epicarp of Citrus, or "dry distillation". The essential oil is then separated from the aqueous phase by physical means [34]. This definition encompasses products obtained always from vegetable raw material, but using other extraction methods, such as using non-aqueous solvents or cold absorption. Thus, we can define four types of products [35]. Essential oils are soluble in alcohol, ether, and fixed oils, but insoluble in water.

LICHENS AS A SOURCE OF NEW MEDICINES

Lichens are an untapped source of biological activities of industrial importance and their potential is yet to be fully explored and utilized. Lichen-derived bioactive compounds hold great promise for biopharmaceutical applications as antimicrobial, antioxidant and cytotoxic agents and in the development of new formulations or technologies for the benefit of human life. Lichentherapy or Ethnolichenology is a branch of ethnobotany that studies the uses that man makes of lichens traditionally [36]. Lichens are used for many different medicinal purposes, but there are some general categories of use that reoccur across the world. Lichens are often drunk as a decoction to treat ailments relating to either the lungs or the digestive system [36]. This is particularly common in the Himalayas and south-eastern China. Many other uses of lichens are related to treating gynaecological diseases. This may be related to the common use of lichens for treating sexually transmitted infections and aliments of the urinary system. Two other uses of lichens that are less common, but reoccur in several different cultures, are the treatment of eye afflictions and use in smoking mixtures [37]. Besides, lichens are often used externally for dressing wounds, either as a disinfectant or to stop bleeding. Other common topical lichen uses are for skin infections and sores, including sores in the mouth [36,37]. Many of the traditional medicinal uses of lichens are probably related to their secondary metabolites, many of which are known to both be physiologically active and act as antibiotics. However, some of the traditional uses of lichens also rely on the qualities of lichen carbohydrates. Many of the traditional uses of lichens involve boiling the lichen to create a mucilage which is drunk for lung or digestive ailments, or applied topically for other issues [38,39]. Other lichen carbohydrates which may be important are the isolichenins and galactomannans, which are widespread across various taxonomic groups of lichens, and the pustulins, that are found in Umbilicariaceae [40-45].

Lichens represent a unique division in the plant kingdom. They have been used in Traditional systems of medicine including Traditional Indian Medicine (TIM), Traditional Chinese Medicine (TCM), Homeopathic and Western Medical Herbals. Lichens have been used in the treatment of diverse diseases like arthritis, alopecia, constipation, kidney diseases, leprosy, pharyngitis rabies, infection, worm and infestation. The medicinal utility of lichens is regarded as the presence of secondary compounds like of usnic acid and atranorin. Animal investigations on lichens have demonstrated antimicrobial, antitumor and immunomodulator activity. One of the reasons for exploring biological compounds in lichens is the potential for medical use. However, much work remains to link medical effects with specific lichen species [46]. Lichens in traditional medicine are most commonly used for treating wounds, skin disorders, respiratory and digestive issues, and obstetric and gynecological concerns. They have been used for both their secondary metabolites and their storage carbohydrates. The European uses of lichens have been exported worldwide and sometimes influence the use of lichens by other cultures (*Usnea* sp. being the most widely used genus in traditional medicine) [47].

Several researchers have discussed the pharmaceutical potential and biological activities of lichen substances. The lichen *Xanthoparmelia scabrosa,* is an ingredient in various aphrodisiac formulations sold in the international market. Traditionally, *Cetraria islandica* was used to treat mild inflammation of the oral and pharyngeal mucosa, dyspepsia, and loss of appetite. In European folk medicine, *Cetraria islandica* was used in cancer treatment [48,49]. In India, *Parmelia chinense* finds applications as a diuretic, as a liniment for headaches and is used in a powdered state to heal wounds, whereas the Tinea (Ringworm) like disease is treated with Parmelia sancti-angeli. *Parmelia nepalense* is used in Nepal for the treatment of toothache and sore throat. *Usnea longissima* can be used as a natural antioxidant or antitumor agent [40-45].

FUTURE PROSPECT OF LICHENOLOGY

Lichens are found on every continent and have a history of use as food, medicine, dyes, livestock feed and for other fields. The pharmaceutical potential of lichens is high and several companies are now attempting to commercialise these unique attributes. Industrial production of lichen metabolites is yet to progress, approaches towards axenic cultivation of the lichen mycobionts have been successfully performed to analyse the secondary metabolites produced by the lichen forming fungi [50]. This has given hope in identifying novel molecules that can be of pharmaceutical importance and in industrial applications. Lichens grow very slowly and hence the optimization of its culturing conditions in the laboratory towards obtaining abundant biomass production is a challenging task [51]. Once this can be solved, access to lichen-derived substances for possible applications in different fields to help in human life can surely be a break through phenomenon. The large scale production of important compounds such as sekikaic acid, salazinic acid, and usnic acid needs further improvements to increase yield of such medically important compounds. Optimal conditions required for the growth of the two partners sharing to produce the lichen need to be further investigated. Techniques such as metabolic engineering, genetic manipulation, as well as other biotechnological approaches should be used to overcome the limited availability of lichens producing medically and industry important compounds [37].

Several studies explored promising activities of Lichens, and those studies were conducted using crude extracts of Lichens. Further research is required in order to isolate and identify bioactive compounds responsible for such biological activities and other industrial application. Moreover, clinical trials and more in-vivo experiments have to be carried out to confirm Lichens capabilities as sources of compounds having medical applications.

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