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REVIEW PAPER

Lichens: traditional use and biological activities

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ABSTRACT

Lichens are a stable symbiotic association between photobiont (algae and/or cyanobacteria) and mycobiont (fungi). They are utilized in traditional medicine for ages and documented in various pharmacopeia throughout the world. India is having a rich diversity of lichen species represented by about 2400 species. The tribal inhabitant around forests and other difficult terrains acquired unique knowledge about the use of much wide flora and fauna. Most of these are either lesser known or unknown to the outside world. The treasure of traditional knowledge if subjected to scientific scrutiny could benefit humankind in many ways. They produce unique secondary metabolites through various metabolic pathways and are known to exhibit a wide array of bioactivities. We have reviewed the literature for traditional knowledge of the lichen species and biological activities reported to study its inter-relationship. It was observed that that still a major percentage of lichens have remained unexplored. These lichens may have immense potential; and if analysed could be used in pharmaceutical, nutraceutical, cosmetic industries, and many more.

Keywords: lichen, biodiversity, bioprospection, secondary metabolites, ethnolichenology

РЕЗЮМЕ

Сутар Р.Р., Гайквад С.Б., Мапари С.В., Бехера Б.С. Лишайники: традиционное использование и биологическая активность. Лишайники представляют собой устойчивую симбиотическую ассоциацию между фотобионтами (водорослями и/или цианобактериями) и микобионтами (грибами). Они используются в традиционной медицине на протяжении веков и задокументированы в различных фармакопеях по всему миру. Индия обладает богатым разнообразием видов лишайников, представленных примерно 2400 видами. Жители племен, населяющих леса и другие труднодоступные местности, приобрели уникальные знания об использовании представителей флоры и фауны. Большая часть этих знаний либо менее известна, либо неизвестна в современном мире. Сокровища традиционных знаний, если их подвергнуть научному анализу, могла бы принести человечеству пользу во многих отношениях. Лишайники производят уникальные вторичные метаболиты посредством различных метаболических путей и, как известно, проявляют широкий спектр биологической активности. Мы рассмотрели литературу по традиционным знаниям о видах лишайников и их биологической продукции. Было отмечено, что до сих пор значительная доля лишайников остается неисследованной. Лишайники могут обладать огромным потенциалом; и если бы анализ был проведен, его можно было бы использовать в фармацевтической, нутрицевтической, косметической промышленности и многих других отраслях.

Ключевые слова: лишайник, биоразнообразие, биопроспекция, вторичные метаболиты, этнолихенология

Переведено редколлегией

Biodiversity is a natural resource for developing new highly significant products for food, cosmetics, medicine and others. The tribes inhabiting forests and other hardly accessible areas accumulated unique knowledge about the use of many species of plants, fungi and animals, while urban people often know much lesser about the sources of raw materials for different industries. This knowledge is at verge of losing out thus ought to be preserved and needs to be scientifically examined for human benefit (Pushpangadan et al. 2018). Traditional knowledge refers to the knowledge accumulated over the years and transmitted through generations over time. In the world, the 36 areas with highest biodiversity also known as 'Biodiversity Hot Spots' are recognised, of which four hotspots are in Indian subcontinent, namely Western Ghats, Eastern Himalaya, Indo-Burma and Sundaland (Champion & Seth 1968). Biodiversity of the world is facing threat to depletion because of over-utilization and human destructive activities. Ethnobotany is thus a tool to preserve this ancient wealth of folklore possessed by natives (Pushpangadan et al. 2018).

Lichens are one of the least studied groups of organisms both in taxonomic terms and in terms of the possibilities of their use in medicine and food production. Within four biodiversity hotspots situated in India, over 2000 lichen species have been documented at present. Lichens are formed by a symbiotic association between

mycobiont (fungi) and photobiont (algae and/ or cyanobacteria). Lichens produce unique secondary metabolites through various metabolic pathways. Lichens are known to be pollution indicators and also produce more than 1200 different metabolites that are unique to them and not found in other organisms. These metabolites help to protect themselves from different microbes and also show many biological activities. Many of the isolated lichen metabolites are investigated by scientists and have shown anticancer, antibacterial, anti-inflammatory, antifungal and other activities (Dembetsky 2017).

The lichen species having traditional knowledge and biological activities are reported in Table 1.

Nowadays, it is highly necessary to preserve this knowledge through documentation and its *ex-situ* preservation for the benefit of mankind. The records of traditional knowledge may help in bio-prospection studies in various fields of medicine, nutrition, cosmetics, dyeing industry and perfumery, etc., that may substitute for the chemically synthesized products which are sometimes harmful and also have major side-effects as reported in many review papers (Fig. 1, 2).

Ethnobiology has grown increasingly, and the scientific knowledge about organisms is used for medicinal purposes. It made the researchers be aware of the substances found in organisms in order to produce new drugs (Posey 1992). In this regard, lichens have been extensively studied with particular emphasis on pharmacological potential and ethno-lichenological studies on the basis of survey work conducted (Sharma et al. 2021).

Based on the above background we have reviewed the literature for traditional knowledge of the lichen species available and their biological activities reported to study their inter-relationships. This documentation may help in sustainable use of valuable lichens and their preservation, and may assist in targeting and selecting species for future pharmacological research too.

This review is compiled from relevant databases, published research papers, books and book chapters. The keywords used while mining the data on internet were 'traditional knowledge', 'lichen ethnobiology', 'lichen folklore of India', 'biological activities of lichen extracts', 'lichen biodiversity' and similar.

India constitutes approximately 11 % of the world's total lichen species diversity. The present survey contributes to study the available traditional knowledge of Indian lichens and known to date biological activities. It was observed that 39 % lichen species were having both traditional use as well as reported biological activity; whereas 12 % of lichens have traditional importance and are yet to be studied for biological activities; and nearly 49 % lichen species have been reported for their biological activities and unknown traditional use so far. It is evident that still a major percentage of lichens have remained un-noticed. These lichens may have immense potential; and if analyzed could be used in pharmaceutical, nutraceutical, cosmetic industries and many more.

Furthermore, lichens are commercially sold as spice and condiment. Certain Ayurvedic and Unani medicines sold in Indian markets under the trade names Chharila and Ushna, respectively, are composed of different species of lichens. Lichens can be found for sale in grocery shops as Chharila in most cities in India (Upreti et al. 2005). Usnic acid as a pure substance is used in creams, toothpaste, mouthwash, deodorants, and sunscreen products, in some cases as an active principle, in others as a preservative (Cansaran et al. 2007).

Nowadays, there are few companies that use the lichen compounds for production of medicines/nutraceuticals under registered trademarks and sell them on various online websites.

Usnea barbata is one of the ingredients of deodorant by Earth Science Naturals (California, USA). Powdered extracts of lichens *Xanthoparmelia scrabosa*, *Usnea barbata* and *Cetraria islandica* are sold online by NutriCargo, LLC. (Wholesale Botanical, Clifton US). Thallus extracts of *Cetraria islandica*, *Cladonia rangiferina*, *Usnea* spp. (*U. barbata*, *U. subfloridana*, *U. filipendula*) and *Lobaria pulmonaria* are used in a syrup which supports body's natural defence system and upper respiratory system under the brand name of Melato di Licheni (Weleda, UK).

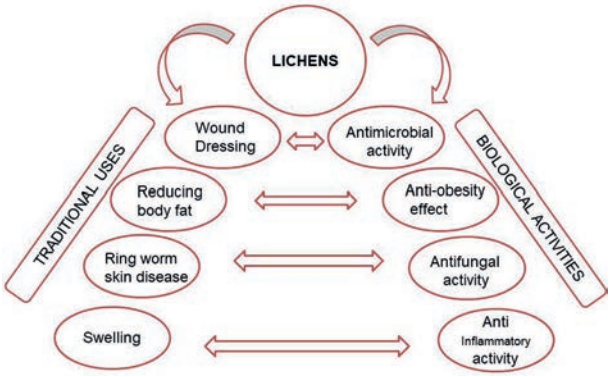

Figure 1 Traditional use and biological activities of lichens

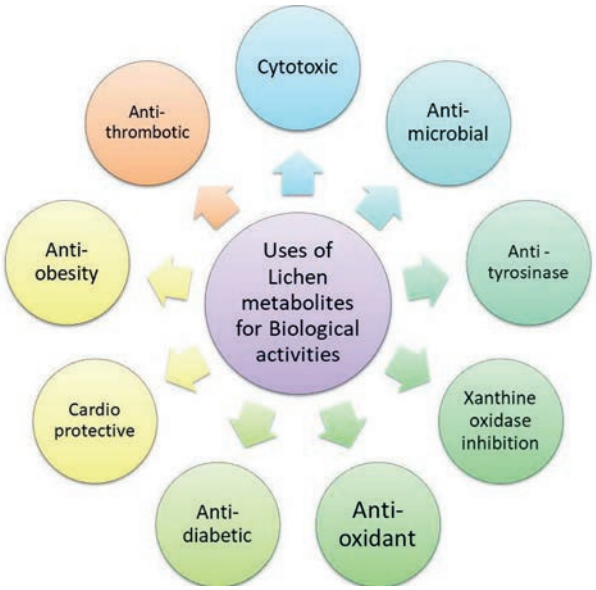

Figure 2 Biological activities of lichens

Table 1: Lichen species, their traditional use and biological activities reported.

Species name	Traditional knowledge	Biological activities	References
Acarospora gobiensis H. Magn.	Not reported	Antimicrobial	Řezanka 1999
Acroscyphus sphaerophoroides Lév.	Not reported	Antibacterial	Nayaka 2010
Alectoria ochroleuca (Hoffm.) A. Massal.	Decoction is used for treating chapped skin on babies or the feet of adults	Cancer chemo preventive, cytotoxic, antifungal	Jain 2016, Ingolfsdottir et al. 2000, Lauterwein et al. 1995
Alectoria sarmentosa Ach.	Used for wound dressing, open sore, sanitary napkins and baby diapers. Also used to treat asthma, arthritis, and excessive discharge of mucus from nose or throat	Antifungal, antimicrobial	Jain 2016, Rankovic 2007b, Gollapudi 1994
Arthoraphis alpina (Schaer.) R. Sant.	Not reported	Anticancer	Perry et al. 1999
Arthothelium awasthii Patw. & Kulk.	Not reported	Antioxidant, tyrosinase enzyme	Verma et al. 2008a,b
Bryoria asiatica (Du Rietz) Brodo & D. Hawksw.	In China it is used in general for weakness, dizziness, heart palpitation, involuntary ejaculation, night sweats, and difficulty in urinating, contagious skin disease, draining pus	Not reported	Wang & Qian 2013
Bryoria bicolor (Ehrh.) Brodo & D. Hawksw.	In China it is used in general for weakness, dizziness, heart palpitation, involuntary ejaculation, night sweats, and difficulty in urinating, contagious skin disease, draining pus	Not reported	Wang & Qian 2013
Buellia subsoriroides S. Singh & D.D. Awasthi	The paste of the thalli is used to make henna tattoo on palms and lips	Not reported	Jain 2016
Bulbothrix setschwanensis (Zahlbr.) Hale	Used as spice in Northern India and also for Dye yielding	Antityrosinase, xanthine oxidase inhibition, antimicrobial, antioxidant, cytotoxic, antifungal	Behera BC 2002, Maurya 2018, Fernandez 2016, Tiwari 2011
Canoparmelia aptata (Kremp.) Elix & Hale	Not reported	Antibacterial, antioxidant, cytotoxic	De Jesus 2016
Canoparmelia texana (Tuck.) Elix & Hale	Sold as spice from Uttaranchal and Uttar Pradesh	Mitodepressive, clastogenic	Upreti et al. 2005, de Campos 2008
Cetraria aculeata (Schreb.) Fr.	Not reported	Antimutagenic, antioxidant, antimicrobial	Ceker 2018, Turk et al. 2003
Cetraria islandica (L.) Ach.	Used as tonic to treat pulmonary tuberculosis, coughing blood, asthma, chronic congestion, laxative, indigestion and dysentery, uterine cysts, kidney stones and urinary tract infection. Food for reindeers in winter	Inhibition of 5-lipoxygenase, antiproliferative, cytotoxic, antimicrobial, antimycobacterial, inhibition of DNA polymerase, inhibitor of human keratinocyte cell line, antioxidant, antitrypanosomal	Crawford 2015, Ingolfsdottir 1994,1997,1998, 2000, Haraldsdottir et al. 2004, Turk et al 2003, Gülçin 2002, Ogbaji 2014
Cetraria laevigata Rass.	Not reported	Antitumour	Wang 1991
Cetrelia braunsiana (Müll. Arg.) W.L. Culb. & C.F. Culb.	Not reported	Antioxidant, cytoprotective, antifungal	Fernandez 2015, Wei et al. 2008
Cetrelia collata (Nyl.) W.L. Culb. & C.F. Culb.	This species along with other species of Parmelioid lichens (*Melanelia infumata*, *Everniastrum cirrhatum* and *Parmotrema nilgherrense*) is commercially used in perfume industry in Uttar Pradesh	Not reported	Jain 2016
Cetrelia olivetorum (Nyl.) W.L. Culb. & C.F. Culb.	Not reported	Antimutagenic, antioxidant, prolyl endopeptidase inhibitory (PEPI), antimicrobial	Ceker et al. 2018, Savale et al. 2015
Cetrelia pseudolivetorum (= Asahina) W.L. Culb. & C.F. Culb.	In China it is used to treat blurred vision, bleeding from uterus, bleeding from external injury, chronic dermatitis and sores and swelling	Antibacterial, amylase inhibitory, antioxidative, antimicrobial, anticancer, antiinflammatory, antifungal	Wang & Qian 2013, Karagöz 2009, Thadhani & Karunaratne 2017, Cilerdžić 2016, Kosanić et al. 2012a, Huang 2014, Wei et al. 2008
Chrysothrix chlorina (Ach.) J.R. Laundon	In the state of Jammu and Kashmir, India used for dyeing	Not reported	Haq et al 2012
Cladia aggregata (Sw.) Nyl	Not reported	Antimicrobial, anticancer, antityrosinase	Martins et al. 2010, Perry et al. 1999, Yamamoto et al. 1998
Cladonia amaurocraea (Flörke) Schaer.	Used in China for headaches and dizziness	Antifungal	Jain 2016, Guo 2017
Cladonia arbuscula (Wallr.) Flot.	Reindeer use it as food in winters	Antibiotic, antimycobacterial	Ivanova & Ivanov 2009, Vartia 1973, Ingolfsdottir 1998
Cladonia cartilaginea Müll. Arg.	It is reported to have medicinal uses such as relief from cough and cold	Not reported	Singh et al 2018
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	Decoction used to treat whooping cough	Antimutagenic, antioxidant	Nayaka 2010, Ceker et al. 2018
Cladonia crispata (Ach.) Flotow	Not reported	Antitumor	Nishikawa 1974

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Cladonia deformis (L.) Hoffm.	In Finland used in traditional medicine for pulmonary tuberculosis and cough	Not reported	Vartia 1973
Cladonia fenestralis Nuno	Used as medicine for bacterial infections on skin, dizziness, nose bleeding, contagious skin disease and conjunctivitis	Not reported	Wang & Qian 2013
Cladonia fimbriata (L.) Fr.	Not reported	Antimicrobial, anticancer	Perry et al. 1999
Cladonia fruticulosa Kremp.	Used as medicine for bacterial infections on skin, dizziness, nose bleeding, contagious skin disease and conjunctivitis	Not reported	Wang & Qian 2013
Cladonia furcata (Huds.) Schrad.	Not reported	Antimicrobial, cancer chemopreventive, cytotoxic, antifungal	Rankovic 2007a, Ingolfsdottir et al. 2000, Wei et al. 2008
Cladonia gracilis (L.) Willd.	Forage for reindeer during winter	Antibacterial	Storeheier et al. 2002, Angelique et al. 2010
Cladonia macilenta Hoffm.	Not reported	Acetylcholinesterase inhibitor	Luo et al. 2013
Cladonia nivalis	Forage for reindeers in winter	Not reported	Storeheier et al. 2002
Cladonia ochrochlora Flörke	Not reported	Bactericidal	Verma 2011
Cladonia pyxidata (L.) Hoffm.	In homeopathy used to treat anxiety	Antioxidant, antimicrobial, anticancer	Rogers 2014, Kosanić et al. 2014
Cladonia rangiferina (L.) F.H. Wigg.	Dried thalli powder applied on skin for curing of eczema and relieves joint pain. Forage for reindeer during winter. Also called reindeer moss.	Antifungal, antitumor, cancer chemopreventive, cytotoxic, antioxidant, antityrosine	Sinha 2005, Rankovic 2007b, Nishikawa 1974, Ingolfsdottir et al. 2000, Yamamoto et al. 1998
Cladonia scabriuscula (Delise) Nyl.	Used for treatment of vaginal discharge/bleeding	Free radical scavenging, antibacterial, antifungal	Jain 2016, Pandey et al. 2018, Wei et al. 2008
Cladonia stellaris (Opiz) Pouzar & Vězda	Forage for reindeer during winter	Not reported	Storeheier et al. 2002
Coccocarpia erythroxyli (Spreng.) Swinscow & Krog	Not reported	Antimicrobial, antioxidant	Vinayaka 2017, Luo et al. 2010b
Coccocarpia palmicola (Sprengel) Arvid. & Galloway	Not reported	Anticancer	Perry et al. 1999
Collema flaccidum (Ach.) Ach.	Not reported	Antitumor	Řezanka 2006
Dermatocarpon miniatum (L.) Mann	Used to treat dermal blemishes and dry skin accumulation	Antioxidant, antimicrobial	Bhanumathi 2000, Aslan et al. 2006
Diploschistes scruposus (Schreb.) Norman	Not reported	Antioxidant, antibacterial	Sokmen et al. 2012
Dirinaria applanata (Fée) D.D. Awasthi	Not reported	Radical scavenging, antimicrobial, insecticidal efficiency	Prashith Kekuda, et al. 2015
Dirinaria consimilis (Stirt.) D.D. Awasthi	In folklore is known to treat inflammation	Antiinflammatory, cytotoxic	Tatipamula 2017, 2018
Evernia divaricatica (L.) Ach.	Not reported	Antimicrobial	Aslan et al. 2006
Evernia mesomorpha Nyl.	Used for treatment of pneumonia, pulmonary tuberculosis, hepatitis, headache, infection, inflammation of breasts, and snake bites	Antimicrobial	Crawford 2015, Oh JM 2018
Everniastrum nepalense (Taylor) Hale ex Sipman	Thalli boiled, fried and eaten as vegetables and also used for treatment of toothache and sore throat	Antifungal, antioxidant	Sinha 2005, Shah 2014, Tiwari 2011, Maharjan 2013
Everniastrum cirrhatum (Fr.) Hale ex Sipman	Widely used as spices, food, and medicines. Used to make a crude drug named 'Chharila' applied to wounds, diseases of the blood and heart, stomach disorders, enlarged spleen, bronchitis, bleeding piles, dyspepsia, scabies, leprosy, sore throat, toothache and pain in general, kidney stones, painful urination, haemorrhoids, lack of menstruation, menstrual pain, broken bones, rheumatism, reducing swelling. It is also used as a carminative, aphrodisiac, diuretic, sedative and astringent.	Antioxidative, cardioprotective, anticancer, antifungal, cytotoxic, antiobesity (pancreatic lipase inhibitory), antimicrobial, anti-helmintic, insecticidal, anti-mycobacterial, antibacterial, amylase inhibitory	Jain 2016, Pol et al. 2017, Prashith Kekuda et al. 2012, Anil 2011, Swathi et al. 2010, Gupta 2007, Joshi 2011, Nayaka 2010, Thadhani 2017
Everniastrum vexans (Zahlbr.) Hale ex Sipman	Not reported	Antibacterial, antifungal	Plaza 2018
Flavocetraria cucullata Kärnefelt & A. Thell	In Alaska was used as condiment	Anticancer	Ivanova & Ivanov 2009, Upreti et al. 2005, Nguyen 2014
Flavoparmelia caperata (L.) Hale	Its decoction is known to expel intestinal worms	Antioxidant, antimicrobial, antiproliferative, antioxidant, cytotoxic, antibacterial, anti-mycobacterial, amylase inhibitory	Nayaka 2010, Mitrovic 2011, Fernandez 2016, Dieu 2019, Gupta 2007, Thadhani & Karunaratne 2017

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Flavopunctelia flaventior (Stirt.) Hale	Used as spice in North India	Anticancer	Stoyanov 2009, Upreti et al. 2005, Nguyen 2014
Graphina acharii (Fée) Müll. Arg.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina adscribens (Nyl.) Müll. Arg	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina glaucorufa (Vainio) Zahlbr.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina multistriata Miill. Arg	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina norlabiata Patw. & C.R.Kulk.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina nylanderi Patw. & C.R.Kulk.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina perstriatula (Nyl.) Zahlbr.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina salacinilabiata Patw.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphina simulans (Leight.) Muell. Arg.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis ajarekarii Patw. & C. R. Kulk	Not reported	Fibrinolytic, anti-inflammatory, anticancer potency	Tatipamula & Vedula 2020
Graphis assamensis Nagarkar & Patw.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis exalbata Nyl. B.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis garoana Nagarkar & Patw.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis glauconigra Vainio	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis guimarana Vain.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis hossei Vain.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis inamoena Zahlbr.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis inquinata C.Knight & Mitt.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis nakanishiana Patw. & C.R. Kulk.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis patwardhanii Kulk.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis persicina May and Flot.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis persulcata Stirton	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis pyrrhocheiloides Zahlbr	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis scripta (L.) Ach.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis sikkimensis Nagarkar & Patw.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Graphis sorediosa Nagarkar & Patw.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Heterodermia incana (Stirt.) D.D. Awasthi	Paste of thalli used as plaster material in cuts and injuries, used as an antiseptic	Antilipoxygenase, radical scavenging, antimicrobial, antifungal	Tiwari 2011
Heterodermia pseudospeciosa (Kurok.) W.L. Culb.	Paste of thalli used as plaster material in cuts and injuries, used as an antiseptic	Antilipoxygenase, radical scavenging, antimicrobial, antifungal	Behera 2016; Tiwari 2011Balasubramanian 2014
Heterodermia boryi (Fée) Hale	Paste of thalli used as plaster material in cuts and injuries, used as an antiseptic.	Antilipoxygenase, radical scavenging, antimicrobial, antifungal	Behera 2016, Tiwari 2011, Balasubramanian 2014
Heterodermia diademata (Taylor) D.D. Awasthi.	Paste of thalli used as plaster material in cuts and injuries, used as an antiseptic	Antilipoxygenase, radical scavenging, antimicrobial, antifungal	Behera 2016, Balasubramanian 2014
Heterodermia angustiloba (Müll. Arg.) D.D. Awasthi	Paste of thalli used as plaster material in cuts and injuries, used as an antiseptic	Antilipoxygenase, radical scavenging, antimicrobial, antifungal	Sinha 2005
Heterodermia leucomelos (L.) Poelt	Used as flavouring agent; used in wound healing.	Amylase inhibitory	Saklani & Upreti 1992

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Heterodermia podocarpa (Bél.) D.D. Awasthi	Not reported	Lipid peroxidation, tyrosinase enzyme, antioxidant, cytotoxic	Verma et al. 2008a, 2008b, Jha et al 2017
Heterodermia tremulans (Müll. Arg.) W.L. Culb	Used as flavouring agent. Used in wound healing	Amylase inhibitory	Upreti et al. 2005, Thadhani & Karunaratne 2017
Hypogymnia enteromorpha (Ach.) Nyl.	Not reported	Antityrosinase, antioxidant	Yamamoto et al. 1998
Hypogymnia hypotrypa (Nyl.) Rassad.,	In China is used to treat bleeding from uterus, bleeding from external injury, chronic dermatitis and sores	Antioxidant, antimicrobial, antiproliferative	Wang & Qian 2013, Mitrovic 2011
Hypogymnia physodes (L.) Nyl.	In China is used to treat bleeding from uterus, bleeding from external injury, chronic dermatitis and sores	Antioxidant, antimicrobial, antiproliferative	Wang & Qian 2013, Mitrovic 2011
Hypogymnia tubulosa (Schaer.) Havaas	Not reported	Antimicrobial	Cansaran 2010
Hypogymnia vittata (Ach.) Gasilien	Not reported	Antimicrobial	Cansaran 2010
Lasallia pustulata (L.) Mérat	Not reported	Anti-genotoxic, antioxidant, antimicrobial, anticancer	Kosanić et al 2016
Lecanora muralis (Schreb.) Rabenh. em Poelt	Not reported	Antibacterial	Saenz et al. 2006
Leptogium cyanescens (Rabenh.) Koerb.	Not reported	Anticancer	Perry et al. 1999
Leptogium denticulatum Nyl.	Local people from Arunanchal Pradesh boiled thallus which becomes jelly is used as vegetable and also for making soup	Not reported	Rout et al. 2010
Lethariella cladonioides (Nyl.) Krog	Traditional Tibetan health-promoting tea used for reducing blood pressure, body fat, and inflammation. Used against aching back and weak legs, paralysis, menstrual disorders, vaginal discharge, dizziness, impotency and epilepsy	Antiobesity	Jain 2016, Sung 2011
Lobaria isidiosa (Müll. Arg.) Vain.	In China is used for the treatment of indigestion, reducing inflammation, relieving pain, burns and scalds, oedema due to kidney inflammation	Not reported	Crawford 2015
Lobaria japonica (Zahlbr.) Asahina;	Not reported	Antitumor	Takahashi 1974
Lobaria kurokawae Yoshim.	In India mainly used in lung ailments (e.g. tuberculosis, asthma, coughs, spitting blood), but also for liver disorders, as an appetite stimulant, for diarrhoea, for heavy menstrual flow, and to stop bleeding	Antifungal	Crawford 2015, Wang 2009
Lobaria pseudopulmonaria Gyeln.	Not reported	Antitumor	Takahashi 1974
Lobaria retigera (Bory) Trevis	Used as spice in North India	Anti-dermatophytic, antibacterial, antifungal	Upreti et al. 2005, Pathak 2016a
Myelochroa aurulenta (Tuck.) Elix & Hale	Used as spice in North India.	Anti-dermatophytic, antibacterial, antifungal	Luo 2011, Wei et al. 2008
Myelochroa entotheiochroa (Hue)	Not reported	Antioxidant	Yamamoto et al. 1998, Wei et al. 2008
Myelochroa irrugans (Nyl.) Elix and Hale	Not reported	Antityrosine, antifungal	Yamamoto et al. 1998, Wei et al. 2008
Mykoblastus sanguinarius (L.) Norman	Not reported	Antioxidant	Yamamoto et al. 1998, Wei et al. 2008
Nephroma expallidum (Nyl.) Nyl.	Not reported	Cancer chemopreventive, cytotoxic	Ingolfsdottir et al. 2000
Nephromopsis pallescens (Schaer.) Park	Used as spice in North India	Anti-dermatophytic, antibacterial, antifungal	Luo 2011, Wei et al. 2008
Parmelaria subthomsonii D.D. Awasthi	Used as spice in North India	Anti-dermatophytic, antibacterial, antifungal	Luo 2011, Wei et al. 2008
Parmelaria thomsonii (Stirt.) D.D. Awasthi	Smoke of thalli used for relief from eye pain	Antifungal	Sinha 2005, Tiwari 2011
Parmelia saxatilis (L.) Ach	In China is used to treat blurred vision, bleeding from uterus, bleeding from external injury, chronic dermatitis and sores and swelling	Antibacterial, amylase inhibitory, antioxidative, antimicrobial, anticancer, antiinflammatory, antifungal	Wang & Qian 2013, Karagöz 2009, Thadhani & Karunaratne 2017; Cilerdžić 2016, Kosanić et al. 2012a, Huang 2014, Wei et al. 2008
Parmelia sulcata Taylor	To relieve discomfort, applied on gums of teething babies. Used in the treatment of pulmonary and cranial diseases	Antioxidant, antimicrobial, antiproliferative, anticancer	Jain 2016, Mitrovic 2011, Kosanić et al. 2012a
Parmelinella wallichiana (Taylor) Elix & Hale	Used as spice in Maharashtra, India	Not reported	Upreti et al. 2005
Parmotrema abessinicum (Kremp.) Hale	Not reported	Antioxidant, cytoprotective	Fernandez 2015

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Parmotrema austrosinense (Zahlbr.) Hale	Not reported	Beta-glucosidase inhibitor, antimicrobial, antibacterial, antifungal	Lee & Kim 2000, Balaji & Hariharan 2007
Parmotrema chinense (Osbeck) Hale & Ahti	Widely used as spices, food, and medicines. Used to make a crude drug named 'Chharila' applied to wounds, diseases of the blood and heart, stomach disorders, enlarged spleen, bronchitis, bleeding piles, dyspepsia, scabies, leprosy, sore throat, toothache and pain in general, kidney stones, painful urination, haemorrhoids, lack of menstruation, menstrual pain, broken bones, rheumatism, reducing swelling. It is also used as a carminative, aphrodisiac, diuretic, sedative and astringent	Antioxidative, cardioprotective, anticancer, antifungal, cytotoxic, antiobesity (pancreatic lipase inhibitory), antimicrobial, anthelmintic, insecticidal, antimycobacterial, antibacterial, amylase inhibitory	Jain 2016, Pol et al. 2017, Prashith Kekuda, et al. 2012, Anil 2011, Swathi et al. 2010, Gupta 2007, Joshi 2011, Nayaka 2010, Thadhani 2017
Parmotrema hababianum (Gyeln.) Hale	Used as spice, relieves kidney disorder or venereal diseases and as medicine for skin diseases. The fresh plant is burnt and ash is mixed with mustard or linseed oil, used for ringworm like skin disease	Anti-hyperglycemic, antioxidant	Upreti et al. 2005, Ganesan 2016
Parmotrema nilgherrense (Nyl.) Hale	Used as spices, food, and medicines. Used to make a crude drug named 'Chharila' applied to wounds, diseases of the blood and heart, stomach disorders, enlarged spleen, bronchitis, bleeding piles, dyspepsia, scabies, leprosy, sore throat, toothache and pain in general, kidney stones, painful urination, haemorrhoids, lack of menstruation, menstrual pain, broken bones, rheumatism, reducing swelling. It is also used as a carminative, aphrodisiac, diuretic, sedative and astringent.	Antioxidative, cardioprotective,, anticancer, antifungal, cytotoxic, antiobesity (pancreatic lipase inhibitory), antimicrobial, anthelmintic, insecticidal, antimycobacterial, antibacterial, amylase inhibitory	Jain 2016, Pol et al. 2017, Prashith Kekuda et al. 2012, Anil 2011, Swathi et al. 2010, Gupta 2007, Joshi 2011, Nayaka 2010, Thadhani 2017
Parmotrema praesorediosum (Nyl.) Hale	Not reported	Beta-glucosidase inhibitor, antimicrobial, antibacterial, antifungal	Lee & Kim 2000, Balaji & Hariharan 2007
Parmotrema rampoddense (Nyl.) Hale	Not reported	Antibacterial	Pillai 2015
Parmotrema reticulatum (Taylor) M. Choisy	Used as spice, relieves kidney disorder or venereal diseases and as medicine for skin diseases. The fresh plant is burnt and ash is mixed with mustard or linseed oil, used for ringworm like skin disease	Anti-hyperglycemic, antioxidant	Upreti et al. 2005, Ganesan 2016
Parmotrema saccatilobum (Taylor) Hale	Not reported	Antioxidant, cytoprotective	Fernandez 2015
Parmotrema sanctiangelii (Lynge) Hale	Used as spice, relieves kidney disorder or venereal diseases and as medicine for skin diseases. The fresh plant is burnt and ash is mixed with mustard or linseed oil, used for ringworm like skin disease	Antioxidative, cardioprotective, anticancer, antibacterial, bactericidal	Crawford 2015, Pol et al. 2017, Pillai 2015, Brij Lal & Upreti 1995, Verma 2011
Parmotrema stuppeum (Taylor) Hale	Not reported	Antioxidant	Jayapraksha & Rao 2000
Parmotrema subtinctorium (Zahlbr.) Hale	In China used for bleeding from external injury, localized swelling and pain	Antibacterial, antioxidant, antiglycation, inhibitory, antifungal	Crawford 2015, Jain 2016, Pillai 2015
Parmotrema tinctorum (Despr. ex Nyl.) Hale	Used as spice and flavouring agents. Used for bleeding from uterus and from external injuries, sores and swelling, chronic dermatitis and localized swelling	Antibacterial, antioxidant, antiglycation, inhibitory, antifungal	Raj 2014, Prashith Kekuda 2016a
Peltigera canina (L.) Willd.	In India is used as tonic and medicine for treatment of rabies and Jaundice and for soothing swelling of tonsils	Anti-proliferative	Jain 2016, Munzi 2014
Peltigera dolichorhiza (Nyl.) Nyl.	Not reported	Cytotoxic	Perry et al. 1999
Peltigera horizontalis (Huds.) Baumg	Not reported	Genotoxic, antigenotoxic, antioxidant	Nardemir 2013
Peltigera leucophlebia (Nyl.) Gyelin.	Not reported	Cancer chemopreventive, cytotoxic, antibacterial, inhibition of 15-lipoxygenase, 5-lipoxygenase	Ingolfsdottir et al. 2000
Peltigera polydactylon (Neck.) Hoffm.	Paste of thalli applied on cut injury to stop bleeding	Not reported	Sinha 2005
Peltigera praetextata (Flörke) Zopf	In the state of Jammu and Kashmir, India, used for dyeing wool	Genotoxic, antigenotoxic, antioxidant, antiproliferative	Haq et al. 2012, Nardemir 2013, Munzi 2014
Peltigera rufescens (Weiss.) Humb.	Not reported	Antioxidant	Odabasoglu et al. 2005
Phaeographina caesiopruinosa (Fée) Müll.Arg.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Phaeographina noralboradians Patw. & C.R. Kulk.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Phaeographiopsis indica (Patw. and Nag.) Sipman and Aptroot	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Phaeographis angulosa Müll. Arg.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Phaeographis submaculata Zahlbr.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Phaeographis subritigrina (Vainio) Zahlbr.	Not reported	Antityrosinase, xanthine oxidase, antioxidant	Behera et al. 2003, 2004, 2006
Physcia aipolia (Ehrh. ex Humb.) Fürnr.	Not reported	Antimicrobial	Cobanoglu 2016
Pseudocyphellaria aurata (Ach.) Vain.	In African continent used as tea to treat indigestion	Antifungal	Crawford 2015, Shivanna 2016
Punctelia borreri (Sm.) Krog	In China is used to treat blurred vision, bleeding from uterus, bleeding from external injury, chronic dermatitis and sores and swelling	Antibacterial, amylase inhibitory, antioxidative, antimicrobial, anticancer, antiinflammatory, antifungal	Wang & Qian 2013, Karagöz 2009; Thadhani & Karunaratne 2017, Cilerdžić 2016, Kosanić et al. 2012a, Huang 2014, Wei et al. 2008
Punctelia rudecta (Ach.) Krog.	Not reported	Antibacterial	Nayaka 2010
Ramalina conduplicans Vain	In central Indian regions used as spice and flavouring agents and also as efficacious medicine for hydrophobia and jaundice	Antioxidant, antibacterial, antifungal, amylase inhibitory	Jain 2016, Luo 2010a, Ankith 2017, Thadhani & Karunaratne 2017
Ramalina farinacea (L.) Ach.	Not reported	Antimicrobial, antifungal, antibacterial, cytotoxic	Tay et al. 2004, Esimone et al. 1999, 2005
Ramalina pacifica Asahina	Traditionally used to treat urinary tract and respiratory infections and pneumonia	Inhibition of tyrosine	Gayathri & Swamy 2012, Yamamoto et al. 1998
Ramalina pollinaria (Westr.) Ach	Not reported	Antimicrobial	Cansaran et al. 2007
Ramalina roesleri (Hochst.) Hue	Used for treatment of traumatic injuries, bleeding and swelling	Antibacterial, antioxidant, antifungal	Crawford 2015, Sisodia 2013, Goel 2011
Ramalina sinensis Jatta	Sold as spice in Uttaranchal, Uttar Pradesh and Himachal Pradesh	Antifungal	Upreti et al. 2005, Oh et al. 2006
Ramalina subfarinacea (Nyl.) Nyl.	Not reported	Antibacterial	Saenz et al. 2006
Rhizocarpon geographicum (L.) DC.	Used for dyeing of woollens.	Not reported	Rogers 2014
Rhizoplaca chrysoleuca (Sm.) Zopf	In India used for dyeing purpose. In China it is used for the treatment of tuberculosis, intestinal obstruction, burns and scalds, skin infections and pain relief. Applied externally or taken orally.	Not reported	Wang & Qian 2013, Haq et al. 2012
Roccella montagnei Bel. D.D. Awasthi	Not reported	Antioxidant, antiinflammatory, anticancer, acute toxicity studies, antimicrobial, antimutagenic	Tatipamula 2019, Balaji et al. 2006, Naik et al. 2016
Solorina crocea (L.) Ach.	Not reported	Cancer chemopreventive, cytotoxic	Ingolfsdottir et al. 2000
Stereocaulon alpinum Laurer	Not reported	Antioxidant, antibacterial	Nayaka 2010
Stereocaulon foliolosum Nyl.	Used for Urinary trouble, blister of the tongue	Anti-mycobacterial	Saklani & Upreti 1992, Gupta 2007
Stereocaulon himalayense D.D. Awasthi & I.M. Lamb	Decoction used to treat burning sensation during urination along with other urinary troubles	Antifungal	Sinha 2005, Goel 2011
Stereocaulon macrocephalum Müll. Arg.	Mature thalli are dried under the sun, used for treating burns and pus exudates and help in healing process	Not reported	Hynniewta 2008
Sticta nylanderiana Zahlbr.	Crushed thalli taken orally for relief from excessive cough	Antioxidant	Sinha 2005, Luo et al. 2010b
Stereocaulon paschale (L.) Hoffm.	Forage for reindeer during winter.	Antioxidant, antimicrobial and anticancer	Storeheier et al. 2002, Ranković et al. 2014
Sulcaria sulcata (Lév.) Bystrek ex Brodo & D. Hawksw.	Used for dizziness, kidney infections, weakness, heart palpitation, night sweating, oedema, skin diseases and sores. It is also used from the relief from aching back and legs, traumatic bleeding, menstrual irregularities, descending uterus, epilepsy, paralysis. Drink decoction or apply to affected area.	Not reported	Wang & Qian 2013
Sulcaria virens (Taylor) Bystrek ex Brodo & D. Hawksw.	Used for dizziness, kidney infections, weakness, heart palpitation, night sweating, oedema, skin diseases and sores. It is also used from the relief from aching back and legs, traumatic bleeding, menstrual irregularities, descending uterus, epilepsy, paralysis. Drink decoction or apply to affected area.	Not reported	Wang & Qian 2013

Table 1. Continued.

Species name	Traditional knowledge	Biological activities	References
Thamnolia vermicularis (Sw.) Ach. Ex Schaer.	Used for removing of helminths from stomach, coughs, sore throat, inflammation, high blood pressure, fevers, and epilepsy	Antioxidative, antiobesity	Jain 2016, Luo et al. 2006, Choi et al. 2017
Umbilicaria cylindrica (L.) Delise ex Duby	Washed thalli fried and consumed as vegetables	Antimicrobial, antioxidant, anticancer	Sinha 2005, Rankovic 2007a, Kosanić et al. 2012b, Luo et al. 2010b
Umbilicaria indica Frey	Washed thalli fried and consumed as vegetables	Antimicrobial, antioxidant, anticancer	Sinha 2005, Rankovic 2007a, Kosanić et al. 2012b, Luo et al. 2010b
Umbilicaria nanella Frey & Poelt	In China used for indigestion, stomach ache, dysentery, expelling ascarid parasites, vaginal discharge, glomus tumours and reducing swelling	Not reported	Wang & Qian 2013
Umbilicaria vellea (L.) Ach.	In China used for eye infections, bloody faeces and rectal hernia	Antimutagenic	Crawford 2015, Galluce 2011
Usnea aciculifera Vain.*;*	Used for bladder infection, painful urination, urinary retention, swelling in heart and kidneys, bleeding from external injury, relieving pain and bloody faeces. It is also used as remedy of lung troubles, haemorrhage and asthma	Not reported	Jain 2016
Usnea bismolliuscula Zahlbr.	Not reported	Antityrosinase, antioxidant	Yamamoto et al. 1998
Usnea montifuji Mot.,	Not reported	Antityrosinase, antioxidant	Yamamoto et al. 1998
Usnea longissima Ach.	The Baiga tribes of Madhya Pradesh used the species along with other ingredients for treating bone fracture. The Chinese used it as an expectorant in the name "Sun-Lo". In China it is used for stopping sweating dizziness, cold and cough. The species is also used in the treatment of gastric, used to treat cancer, tuberculosis and ulcers	Antimicrobial, cytotoxic, antifungal, antioxidant, antiplatelet, antithrombotic	Jain 2016, Thippeswamy 2011, Yu 2016, Atalay 2011, Lee 2005
Usnea orientalis Motyka	Used as spice in Uttaranchal, Uttar Pradesh and Himachal Pradesh	Antidermatophytic, antifungal	Upreti et al. 2005, Pathak 2016b, Wei et al. 2008
Usnea pectinata Taylor*; U. sikkimensis* Biswas, *U. thomsonii* Stirt.	Used for bladder infection, painful urination, urinary retention, swelling in heart and kidneys, bleeding from external injury, relieving pain and bloody faeces. It is also used as remedy of lung troubles, haemorrhage and asthma	Not reported	Nayaka 2010, Prateeksha et al. 2016.
Usnea subfloridana Stirt.	In Ireland the thalli is mixed with tobacco and butter, boiled, cooled and applied as lotion to eyes for treatment for sore eyes	Antimicrobial	Crawford 2015, Cobanoglu 2016
Usnea undulata Stirt.	Used for treatment of sore throat, bronchitis, cold, flu infections and indigestion	Antimicrobial, antioxidant, antibacterial	Prateeksha et al. 2016, Susithra 2011, Prashith Kekuda 2016b, Nasim 2011
Vulpicida pinastri (Scop.) Mattson & M.J. Lai	In China, used for pulmonary tuberculosis, skin infections, cancer, spasms and to cure venereal diseases like syphilis.	Photoprotective	Crawford 2015;Haq et al 2012; Legouin 2017
Xanthoparmelia conspersa (Ach.) Hale	It is used locally as a snake bite remedy and for treatment of syphilis.	Antioxidant, antibacterial, antifungal	Nayaka 2010, Karaahmet et al. 2019, Sokmen 2018
Xanthoparmelia coreana (Gyeln.) Kurok.	Not reported	Antityrosinase, antioxidant	Yamamoto et al. 1998
Xanthoparmelia pulla (Ach.) O. Blanco	Not reported	Antimicrobial	Aslan et al. 2006
Xanthoparmelia stenophylla (Ach.) Ahti & D. Hawksw.	In Ireland the thalli is mixed with tobacco and butter, boiled, cooled and applied as lotion to eyes for treatment for sore eyes	Antioxidant, antibacterial, cytotoxic	Jain 2016, Kinalioğlu 2016, Kumar 2014
Xanthoparmelia tinctina (Maheu & A. Gillet) Hale	In China it is used to treat blurred vision, bleeding from uterus, bleeding from external injury, chronic dermatitis and sores and swelling.	Antibacterial, amylase inhibitory, antioxidative, antimicrobial, anticancer, antiinflammatory, antifungal	Wang & Qian 2013, Karagöz 2009, Thadhani & Karunaratne 2017, Cilerdžić 2016, Kosanić et al. 2012a, Huang 2014, Wei et al. 2008
Xanthoria elegans (Link) Th. Fr.	Various native tribes use the pigment for face paint	Antibacterial, antigenotoxicity, antifungal	Rogers 2014, Karagoz 2009, Turkez 2012, Wei et al. 2008
Xanthoria fallax (Hepp) Arnold	Not reported	Antioxidant	Yamamoto et al. 1998
Xanthoria parietina (L.) Th. Fr.	Used for the treatment of Jaundice, and used in intermittent fevers	Antiproliferative, antibacterial, antifungal	Nayaka 2010, Basile et al. 2015

CONCLUSION

This is the report after reviewing the pieces of literature on the lichen biodiversity and bioprospection studies available. Lichens are known to possess secondary metabolites and are reported to show various bioactivities. This article may be helpful to the researchers in the field of pharmaceutical sciences so as to explore the new potential natural resource. These reported species data may increase or decrease after a thorough exploration of the biodiversity hotspot and prospecting lichens on the basis of traditional knowledge. This review will help to know the lichen wealth at least in India. Based upon all the experimental results it is evident that lichen metabolites exhibit strong bioactivity and thus can be used as an adjuvant therapy.

Lichens as an important source must be preserved in their habitat by conservation of the host/substratum. They can be grown in laboratories by using different techniques such as spore culture, fragment culture, etc. Synthetic compounds similar to lichen metabolites should be attempted and tested for biological activities for mass production, if reliable.

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