RESEARCH ARTICLE

Geospatial Distribution of Commercially Valuable Lichens in Uttarakhand

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Abstract

In the present study, we have identified commercially significant lichen species from various regions of Uttarakhand Himalaya. The present study emphasizes about 30 commercially valuable lichen species along with their geographical locations across the four studied sites within Uttarakhand state. These species possess potential applications in medicines, ethnic dyes and spices and also serve as valuable bio-indicators. Our findings underscore the therapeutic potential of lichens, with a notable 26 species demonstrating medicinal properties. Among these, eight species exhibited promising antibacterial properties and six showcased antimicrobial potential. Furthermore, seven lichen species were identified as valuable indicators of environmental pollution. Only two species of lichens (*C. fruticulose* and *H. cirrhata*) in the study area were identified as an important source of dyes. Proper conservation and sustainable utilization of these valuable lichens should be ensured in the study area, not only for economic significance but also for advancement in the field of medicine and healthcare.

Keywords: Bio-indicator, Lichen species distribution, Dye yielding and Medicinal lichens, Lichen diversity.

Highlights

- In this study, 30 commercially valuable lichen species were identified within the study area.
- The study concludes that 26 lichen species demonstrated significant medicinal properties, including antibacterial and anticancer potential.
- Five species were used as spice ingredients, two for dye production, and seven as bio-indicator of pollution.
- The geographical locations of these lichens have been mapped and provided in the study.

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Introduction

Lichens are symbiotic organisms of a photosynthetic partner or phycobiont (either alga or cyanobacterium) and a fungal partner (mycobiont). Depending on their habit or growth forms, they are of different types such as foliose (leafy), fruticose (shrubby) and crustose (crust forming). They may grow on a variety of substrates such as bark (corticolous), rock (saxicolous) and soil (terricolous). Lichens are important bioindicators of environmental health due to their sensitivity to changes in air quality, microclimate, and habitat disturbance. The hilly areas of Uttarakhand state located in the western Himalayas, are known for their rich lichen diversity, comprising numerous species that play crucial ecological roles. However, rapid anthropogenic activities pose significant threats to these delicate organisms, making it imperative to study the impact of human-induced disturbances on lichen populations. Anthropogenic activities, such as deforestation, industrialization, and tourism, have resulted in significant alterations to the natural landscape, potentially impacting lichen diversity.

The people residing in hilly areas of Uttarakhand largely depend on surrounding forests to fulfill their livelihood needs such as fuelwood, fodder, medicines, timber, NTFPs, lichen, moss, fungi etc. Forests are the major habitat for the growth and sources of these important resources. But, increasing human disturbance in forests for fodder and fuelwood collection, deforestation, forest fire, encroachment, etc. have influenced the forest's diversity, particularly the lichens of the region.

In Uttarakhand Himalaya, extensive studies have been carried out on the systematic collection of lichen species. But little attention has been paid on the geographical, ecological distribution, habitat destruction and statistical record of lichen flora. A database of about 1038 lichen species belonging to 210 genera and 59 families from Uttarakhand Himalaya has been reported by Arya, *et al*., (2019). The present research article endeavors to shed light on the diverse applications of lichens from medicinal uses to economic and ecological benefits in the study area.

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Materials and Methods

Study Area

The present study was conducted in four hilly areas within Uttarakhand state known for their abundance of lichen species. These areas are identified as follows: Sattal (Site I), Askote-Sandev

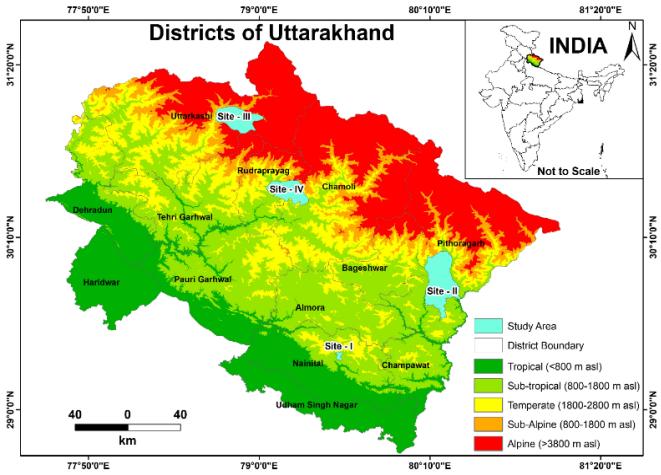

Fig. 1: Location map of the study area

(Site II) (designated a 'Botanical Hot Spot' by Samant *et al*., 1993 due to the occurrence of many rare, endangered, unique plant species and rich biodiversity), Gangotri (Site III), and Chopta-Tungnath (Site IV). All these sites are located within the range of 29° 20′ 59″ to 31° 02′ 05″ N latitude and 78° 40′ 54″ to 80° 19′ 46″ E longitude. (Fig. 1). The elevation of these study sites varies between 1223 to 4296 masl. The geographical location and lichen species richness of these sites are presented in Table 1.

Field Surveys and Lichen Specimen Collection

Field surveys were conducted to identify and document economically significant lichen species. Lichen specimens were collected following standard protocols. GPS coordinates were recorded for each specimen using Garmin Etrex 30.

Laboratory Work

The collected lichen samples were identified using taxonomic keys developed by Awasthi (2007) and expert consultations at the Lichenology Laboratory, CSIR-NBRI, Lucknow. The voucher specimens were deposited at the Biodiversity Conservation Laboratory, Department of Botany, S.S.J. University, Campus Almora (Uttarakhand).

Geospatial Analysis

The mapping of the spatial distribution of identified lichen species was carried out using ArcGIS 10.2.2. To achieve this goal, GPS marking of forest patches was also conducted. The shape files of the study sites were extracted from Google Earth Pro by utilizing GPS points gathered during field observations. Furthermore, shape files for the country, state, and districts were acquired from the Center of Excellence for Natural Resource Data Management System (NRDMS), located at the Department of Geography, S.S.J. Campus, Soban Singh Jeena University, Campus Almora, Uttarakhand. SRTM DEM Data (resampled 30m spatial resolution/ free available/open source) has been applied for elevation and contour mapping.

Results

Commercially Potential Lichens of the Study Area

The present investigation identified commercially useful lichen species of the study area. These species are useful in the preparation of traditional medicine, spices, and perfumery and also as bio-indicators of pollution. A sum of 30 species were identified within the study area. Among these, 26 species were recorded as having medicinal value, with six of them also being used in spices, and two species were found to be used for dye production. Additionally, seven were identified as bioindicator species, with two of them also possessing medicinal value (Fig. 2). The presence of these potential lichens at each study site has been provided in Fig. 3.

Medicinally Valuable Lichens

In the present study maximum 26 species of lichens out of 30 species were observed as medicinally useful. Out of 26 species maximum of eight were represented with their antibacterial properties, followed by six species expressing their antimicrobial and five with their antioxidant properties (Table 2). Besides, three species such as *D. longissima*, *P. nilgherrense* and *R. sinensis* contain antibiotics and three species namely *H. diademata*, *P. reticulatum* and *R. conduplicans* possess their anti-inflammatory

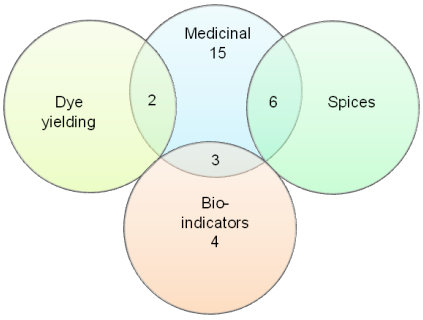

Fig. 2: Number of commercially potential lichen species identified in the present study

Table 1: Geographical location and lichen species richness of the study area

Site	*Site name*	*Sites falls in the district*	**Lichen species richness at site*	*Latitude (N)*	*Longitude (E)*	*Elevation range extracted from SRTM DEM (m asl)*
I	Sattal	Nainital	20	29° 20' 48"	79° 31' 24"	1223-1917
II	Askote-Sandev	Pithoragarh	118	29° 48' 46"	80° 19' 46"	596-3182
III	Gangotri	Uttarkashi	148	30° 55' 34"	78° 40' 54"	2180-6436
IV	Chopta-Tungnath	Chamoli & Rudrprayag	163	30° 29' 00"	79° 12' 18"	937-4296

*Based on the present collection and compilation of secondary data

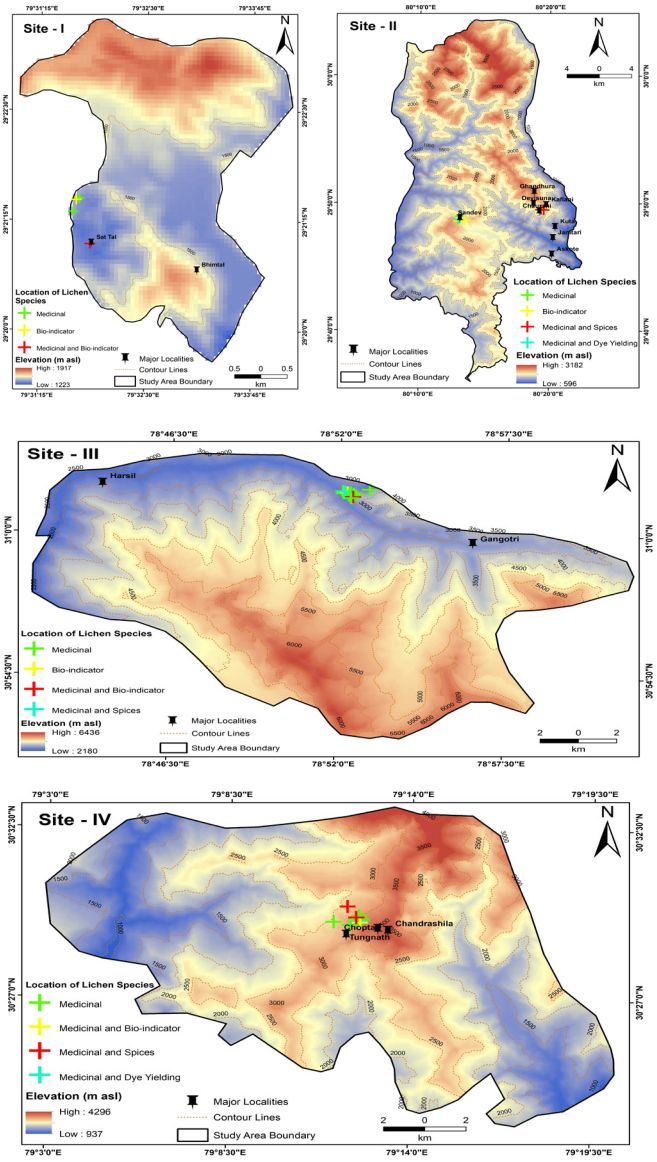

Fig. 3: Location of areas rich in commercially potential lichens across the study sites

qualities. Likewise, two lichen species *D. longissima* and *S. sulcata* show anticancer properties. Only a single lichen species *D. longissima* was also recorded as antitumor (Table 2). Thus, *D. longissimi,* a fruticose lichen occurring on tree barks was observed as a common lichen possessing all the medicinal values and useful against various disorders.

Many lichen species are also applied as a medicine to treat several common diseases such as wound healing, bone fracture, ulcers (*D. longissimi*), whooping cough in children (*C. furcate*), cuts and wounds (*H. diademata*), stomach disorder, bronchitis, fever, swelling, leprosy, bleeding etc. (Table 2).

Lichen Species used as Spice Ingredients

Out of 30 species of commercial lichens only five species, namely *Heterodermia diademata*, *Hypotrachyna nepalensis*, *Parmotrema tinctorum*, *Ramalina sinensis* and *Sulcaria sulcata* were recorded as a flavoring agent and added with spices for taste in Garam

Table 2: An account of lichen species collected from the study area along with their medicinal and other uses

Lichen taxa	*Family*	*Growth form*	*Habitat*	*Study site*	*Latitude (N)*	*Longitude (E)*	*Altitude (m)*	*Potential uses*
Lichens with medicinal value								
Bulbothrix isidiza	Parmeliaceae	Fo	C	I	29° 20′ 59″	79° 31′ 51″	1314	As antioxidant (Stanly *et al*., 2011)
Cladonia fimbriata	Cladoniaceae	Dm	S	III	31° 01′ 36″	78° 52′ 07″	2824	As antioxidant and antimicrobial (Rankovic, *et al*., 2010; Kosanic, *et al*., 2018)
Cladonia fruticulose	Parmeliaceae	Dm	C	II	29°48′42″	80°13′02″	1825	Antibacterial properties (Pius and Sequeira, 2022)
Cladonia furcata	Cladoniaceae	Dm	S	IV	30° 29′ 34″	79° 12′ 25″	3040	Potential as antimicrobial (Rankovic and Misic, 2008; Rankovic, *et al*., 2009; Ingolfsdottir *et al*., 2000)
Cladonia pyxidate	Cladoniaceae	Dm	S	III	31° 01′ 41″	78° 52′ 06″	2783	Used to cure whooping cough in children, fevers and kidney stones, pulmonary tuberculosis (Crawford, 2019)
Dolichousnea longissimi	Parmeliaceae	Fr	C	IV	30° 29′ 60″	79° 12′ 04″	2677	Used in wound healing, bone fractures, ulcers, anticancer, antioxidant, antitumor properties, tuberculosis, antibiotics, lung troubles, hemorrhages, nosebleeds, blisters, strengthening hair (Lal 7and Upreti, 1995; Lans, 2016; D8evkota, *et al*., 2017; Yazici and Aslan, 2003; Odabasoglu, *et al*., 2006; Dandapat and Paul, 2019; Yang, *et al*., 2021; Haq *et al*., 2012)

Heterodermia diademata	Physciaceae	Fo	C	II	29° 49′ 30″	80° 19′ 21″	1889	Used to treat cuts and wounds, anti-inflammatory and antibacterial (Sati and Usman, 1992; Upreti, *et al*., 2005; Devkota, *et al*., 2017; Yang, *et al*., 2021; Haq *et al*., 2012)
Heterodermia obscurata	Physciaceae	Fo	C	IV	30° 29′ 35″	79°12′ 30″	2894	Potential like antioxidant activity, antibacterial (Paudel, *et al*., 2012; Thadhani, *et al*., 2012)
Heterodermia podocarpa	Physciaceae	Fo	C	I	29° 21′ 21″	79° 31′ 39″	1385	antibacterial, cytotoxic activity, antioxidant activity (Jha, *et al*., 2017; Thadhani *et al*., 2012)
Hypotrachyna cirrhata	Parmeliaceae	Fo	C	IV	30° 29′ 33″	79° 12′ 25″	3078	Antimicrobial, antibacterial activities (Pathak, *et al*., 2015; Pius and Sequeira, 2022)
Hypotrachyna nepalensis	Parmeliaceae	Fo	C	II	29° 49′ 29″	80° 19′ 34″	1816	Raw material used for antibiotic (Devkota and *et al*., 2017)
Myelochroa aurulenta	Parmeliaceae	Fo	C	I	29° 21′ 30″	79° 31′ 43″	1379	As anti-dermatophytic and fungicidal uses (Pathak, *et al*., 2016)
Nephromopsis pallescens	Nephromataceae	Fo	C	IV	30° 29′ 30″	79° 11′ 39″	2600	Antibacterial activity and applied on external injury (Luo *et al*., 2011; Yang, *et al*., 2021)
Parmotrema nilgherrense	Parmeliaceae	Fo	C	III	31° 01′ 31″	78° 52′ 18″	3047	Applied to cure stomach disorder, hemorrhoids, bronchitis, fever, headache, toothaches, rheumatism, reducing swelling, leprosy, scabies, soothing irritated skin, sedative, astringent, antiseptic, antibiotic, antimicrobial activity, wound healing (Chanda and Singh, 1971; Kumar and Upreti, 2001; Karadi, 2010; Jveria, *et al*., 2013).
Parmotrema praesorediosum	Parmeliaceae	Fo	C	II	29° 48′ 58″	80° 13′ 10″	1718	Antibacterial property (Mie, *et al*., 2014).
Parmotrema reticulatum	Parmeliaceae	Fo	C	IV	31° 01′ 39″	78° 52′ 21″	2974	Antibacterial and anti-inflammatory properties (Jain, *et al*., 2016).
Parmotrema tinctorum	Parmeliaceae	Fo	C	IV	30° 29′ 42″	79° 12′ 25″	2984	Used in blurred vision, bleeding from uterus, bleeding from external injuries, sores and swelling, chronic dermatitis and localized swelling (Want, *et al*., 2001).
Peltigera canina	Peltigeraceae	Fo	C	III	31° 01′ 45″	78° 52′ 59″	3092	Used in rabies treatment, antibacterial activity and cancer chemo preventive and cytotoxic activity, liver ailments (Ingólfsdóttir, *et al*. 1985; 2000; Romagni and Dayan, 2002; Haq *et al*., 2012).
Peltigera polydactylon	Parmeliaceae	Fo	C	IV	30° 29′ 24″	79° 12′ 08″	2916	To cure wounds and cuts, to stop bleeding and as an antiseptic use (Saklani and Upreti 1992).
Peltigera praetextata	Peltigeraceae	Fo	C	III	31° 01′ 32″	78° 52′ 31″	3240	Antimicrobial properties (Upreti *et al*., 2005).
Ramalina conduplicans	Ramalinaceae	Fr	C	III	31° 01′ 35″	78° 52′ 27″	3145	Antimicrobial, anti-inflammatory uses (Wang, *et al*., 2001; Ankith *et al*., 2017)
Ramalina sinensis	Ramalinaceae	Fr	C	III	31° 01′ 40″	78° 52′ 10″	2806	in antibiotic and antimicrobial preparation (Oh, *et al*., 2006 Yang, *et al*., 2021)

Stereocaulon foliolosum	Stereocaulaceae	Dm	S	IV	30°29′29″	79° 12′ 27″	3123	Antibacterial uses (Gupta *et al*., 2007)
Sulcaria sulcata	Parmeliaceae	Fr	C	IV	30°29′39″	79° 12′ 20″	2972	Anticancer and antioxidant applications (Yamamoto, *et al*., 1998; Yang, *et al*., 2021)
Usnea orientalis	Parmeliaceae	Fr	C	III	31° 01′ 28″	78° 52′ 26″	3135	Anti-dermatophytic property (Pathak, *et al*., 2016)
Usnea subflorida	Parmeliaceae	Fr	C	III	31° 01′ 25″	78° 52′ 22″	3038	Antimicrobial uses (Cansaran *et al*., 2006)
Lichen species used in spices								
Heterodermia diademata	Physciaceae	Fo	C	II	29° 49′ 30″	80° 19′ 21″	1889	Flavoring agent for meat and other food items (Vinayaka and Krishnamurty, 2012)
Hypotrachyna nepalensis	Parmeliaceae	Fo	C	II	29° 49′ 29″	80° 19′ 34″	1816	Raw material used for spices (Devkota *et al*., 2017)
Parmotrema tinctorum	Parmeliaceae	Fo	C	IV	30° 29′ 42″	79° 12′ 25″	2984	Spice and flavoring ingredient for meat and vegetables (Upreti, *et al*., 2005)
Ramalina sinensis	Ramalinaceae	Fr	C	III	31° 01′ 40″	78° 52′ 10″	2806	Fragrant flavor, ingredient of spices (Liu *et al*., 2014; Yang, *et al*., 2021)
Sulcaria sulcata	Parmeliaceae	Fr	C	IV	30°29′39″	79° 12′ 20″	2972	Ingredient of spices (Yang *et al*., 2021)
Dye yielding								
Cladonia fruticulose	Parmeliaceae	Dm	C	II	29°48′42″	80°13′02″	1825	Raw material for dye production (Pius and Sequeira, 2022).
Hypotrachyna cirrhata	Parmeliaceae	Fo	C	IV	30° 29′ 33″	79° 12′ 25″	3078	Raw material used to yield dye (Pius and Sequeira, 2022).
Bio-indicator species								
Bulbothrix isidiza	Parmeliaceae	Fo	C	I	29° 20′ 59″	79° 31′ 51″	1314	Heavy metal (Fe, Cu) accumulation (Begum *et al*., 2009).
Candelaria concolor	Candelariaceae	Fo	C	II	29° 48′ 35″	80°13′ 04″	1861	As bioindicators to assess nitrogen and pollution (Estrabou *et al*., 2011; Thakur and Chander,2018)
Flavoparmelia caperata	Parmeliaceae	Fo	C	III	31° 01′ 38″	78° 52′ 15″	2895	Heavy metal accumulation (Mitrovic, *et al*., 2012; Majumder, *et al*., 2013; Shivanna *et al*., 2015)
Phaeophyscia hispidula	Physciaceae	Fo	C	I	29° 21′ 29″	79° 31′ 41″	1393	Heavy metal accumulation (Shukla and Upreti, 2007; 2009; Gupta *et al*., 2017)
Pyxine berteriana	Caliciaceae	Fo	C	II	29° 48′ 39″	80° 13′ 29″	1830	Pollution monitoring (Abas and Awang, 2017).
Stereocaulon foliolosum	Stereocaulaceae	Dm	S	IV	30°29′29″	79° 12′ 27″	3123	Heavy metal accumulation (Nag, *et al*., 2019).
Usnea orientalis	Parmeliaceae	Fr	C	III	31° 01′ 28″	78° 52′ 26″	3135	Heavy metal (Cd) accumulation (Chettri, *et al*., 2001).

Masala, meat Masala etc. In the present study sites, all these five species were observed as corticolous habitats found on the bark surface of the trees (Table 2).

Dye Yielding Lichens

During the study only two species viz. *C. fruticulose* and *H. cirrhata* were recorded as applied in the preparation of ethnic dyes (Table 2). *Pius* and *Sequeira* (2022) reported that these two lichen species are used as a suitable raw material to prepare local dye.

As Bio-indicator Species and Heavy Metal Accumulators

Lichens are a good indicator of air pollution. In the present study a total of seven lichen species were also recorded as indicator species. These important species are *Bulbothrix isidiza*, *Candelaria concolor*, *Flavoparmelia caperata*, *Phaeophyscia hispidula*, *Pyxine berteriana*, *Stereocaulon foliolosum* and *Usnea orientalis*. These lichen species are useful to assess nitrogen and pollution status (Estrabou, *et al*., 2011; Thakur and Chander, 2018; Abas and Awang, 2017). Besides, five species were also recorded as heavy metal accumulators. *P. hispidula* and *F. caperata,* foliose forms occurred on bark substratum at Sattal and Gangotri region respectively are responsible for accumulating the heavy metals (Nag, *et al*., 2019; Mitrovic, *et al*., 2012; Majumder, *et al*., 2013). Lichen species *B. isidiza* which helps in the accumulation of Fe and Cu (Begum, *et al*., 2009) was also recorded from Sattal forest. Both Sattal and Gangotri regions of Uttarakhand are well-known tourist destinations. Therefore, these two localities are heavily disturbed sites, especially in terms of lichen growth due to frequent vehicle traffic.

Conclusion

In the present study, commercially significant lichen species from various areas of Uttarakhand Himalaya have been mentioned. This also includes their utility and geographical distribution. If these lichen species are systematically harvested and their host trees are protected, they could serve as a sustainable source of income in these areas. Furthermore, the substantial role of these lichen species in medicinal preparation highlights their importance in pharmaceutical research. Proper conservation and sustainable utilization of these lichen resources not only have economic implications but also hold promise for advancements in the field of medicine and healthcare.

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Author Contribution

Balwant Kumar designed the study and drafted the manuscript. Vijay Arya collected data, analyzed, and interpreted the data. Ritika Tamta designed the tables and interpreted the data. Tapan Ghosh made maps using GIS data and software. All the authors critically revised the manuscript and approved the final version of the manuscript for submission.

Conflict of Interest

All the authors declare no conflict of interest.

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