RESEARCH ARTICLE

Biodeterioration Activity of Lichens Communities on Rock Shelters of Bhimbetka World Heritage Zone, Madhya Pradesh, India

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DOI: 10.18811/ijpen.v8i01.07

Abstract

The study deals with lichen diversity on monuments of Bhimbetka rock shelters at Raisen district of Madhya Pradesh. The micro-climatic conditions of the monuments provide excellent habitat for lichens to colonize. A total of 40 species of lichens belonging to 10 lichen communities exhibit their occurrence on the rock shelters. The crustose and squamulose lichen communities with 21 species exhibit their dominance followed by eight Physioid and seven Teloschistacean communities. The ecology of lichen communities colonizing Bhimbetka rock shelters together with their deteriorating and bioprotecting role is also discussed.

Keywords: Monuments, lichens, central India

International Journal of Plant and Environment (2022); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

The lichens are a self-sustaining ecosystem formed by the interaction of an exhabitant fungus and an extracellular arrangement of one or more photosynthetic partners and an indeterminate number of other microscopic organisms Hawkswort & Grube (2020). The peculiar nature of lichens enables them to colonize on variety of substrates including many manmade artefacts. The calcareous rock, stone, bricks or cement and lime plaster (alkaline nature) are excellent substrate, much preferred by a group of lichens known as calcicolous (lime loving) lichens. The calcicolous lichens are unique as they have an inbuilt tolerance to fight against the effect of acidic gases present in the atmosphere. Thus, even in a polluted site where most of the corticolous (bark inhabiting) lichens exhibit their absence, the calcicolous lichens flourish naturally.

Lichens are one of the important agents among biological elements causing damage to the monuments. Various types of lichens colonize on the monuments and historical buildings. The nature and type of construction material, architectural pattern of the monument or building and prevailing climatic condition of the area influence the colonization of lichens to a greater extent. Not all lichens deteriorate the monument, however, they disfigure them by shabby look. The damage by lichens on monuments may be physical or chemical. The physical damage involves the contraction and expansion of the lichen thallus during dry and wet weather conditions respectively. During wet condition the thallus expands and lies flat, strongly attached to the substratum while drying, the thallus lobe curls up with great stress along the peripheral region on substratum. The contraction and expansion of the thallus lobes loosen the particles or fragments of the rock. The root like structures of lichens i.e. rhizines, also lead to similar results during dry and wet conditions.

The lichens commonly produce secondary chemicals, including various weak organic acid, which actively chelate substrate cations, and thus modify the chemical and physical structure of mineral substrata. For example, oxalic acid produced in significant amounts by many lichen species that forms chemical complexes with rock substrata containing calcium carbonate to form the insoluble compound calcium oxalate, which accumulates on the surface and within lichen thalli, or at the lichen rock interface. The residues of calcium oxalate often remain on such substrata, leaving significant and often unsightly white deposits, after the death of the lichen. In case of delicate and intricate rock monuments, calcium oxalate deposits often obscure the detail and historical significance of structures Zopf (1907). Several lichen species typically associated with recovering urban lichen communities appear to be unusually aggressive in exploiting, altering and, in some cases destroying important historical and cultural structures Seaward (2004) and Caneva (2020). Furthermore, some species are able to significantly degrade rock surfaces over relatively short periods of time Saxena *et al.* (2004). The Bhimbetka rock shelters are archaeological sites exhibits the evidence of stone age human life in India. It is the UNESCO world heritage site consisting of seven hills and 750 rock shelters some of which have caves painting of about 10,000 years old. Upreti *et al.*

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How to cite this article: Bajpai, A., Mishra, G.K., Upreti, D.K., Tandon, P.K., Biodeterioration Activity of Lichens Communities on Rock Shelters of Bhimbetka World Heritage Zone, Madhya Pradesh, India. International Journal of Plant and Environment (2022).8(1): 64-71

Source of support: OLP-101

Submitted: 27-01-2022 **Accepted:** 30-02-2022 **Published:** 25-03-2022

(2004) presented the preliminary report on lichen activity over rock shelters of Bhimbetka with 14 species growing over rocks in different localities of the area. The present paper documented the ecology of the lichen communities growing on Bhimbetka rock shelters and their surroundings together with bio deterioration studies.

Materials and Methods

The study is based on lichens recorded from different localities in an around Bhimbetka World Heritage Zone, Raisan district, Madhya Pradesh. The lichens were identified studying their morphology, anatomy and chemistry following the literature of Awasthi (1991 & 2007), Mishra *et al.* (2020), Bajpai *et al.* (2018). The morphology of the taxa was studied under stereo-zoom binocular microscope. The details of thallus anatomy and fruiting bodies were studied by compound microscope. The colour spot tests were carried out on cortex and medulla with the usual chemical reagents such as aqueous potassium hydroxide (K), Steiner's stable paraphenylenediamine (PD) and aqueous calcium hypochlorite (C). Thin layer chromatography was performed for authentic identification of the lichen substances in solvent system A (Toluene: 1-4 dioxane: Acetic acid) following Orange *et al.* (2001).

Results and Discussion

A total of 40 lichen species were recorded from the Bhimbetka rock shelters of which 32 species produced lichen substances having biodeterioration chelating properties. The lichen communities Lecideoid, Teloschistacean and Leprioid, Parmelioid and Physcioid produced a vast array of lichens substance. The common lichen substances such as atranorin, parietin, lecanoric acid, sekaikaic acid, divaricatic acid, zeorin and usnic acid play important (Table 2) role in biodeterioration. *Caloplaca, Buellia, Diploschistes, Dirinaria, Phaeophyscia* and *Pyxine* species are most effective biodeteriorant species of the region, as the species have crustose or squamulose thallus tightly attached to the substratum throughout their whole lower surface and produce a number of chelating chemical substances. *Dirinaria, Pyxine* and *Phaeophyscia* are foliose lichen loosely attached to the substrate in few places with the help of their hair like rhizines on the lower side of the thallus and also produce chelating substances are moderate biodeteriorant (Table 1). The

Table 1 : List of lichens growing on different habitats in Bhimbatika rock shelters.

S.N.	*Habitat*	*Lichen taxa*
1	Damp places (Vertical walls near passage of rock shelters)	*Botryolepraria lesdainii, Collema texanum, Dirinari aaegialita, Endocarpon nanum, Phylliscum indicum, Staurothele fissa* and *Lepraria lobificans*
2	Semi shaded areas	*Buellia disjecta, Dirinaria confluens, Dirinaria consimilis* and *Caloplaca cupulifera*
3	Smooth rocks	*Pyxine petricola, Physcia dimidiata* and *Parmotrema praesorediosum*
4	Exposed sandstones	*Caloplaca cupulifera, Caloplaca orissensis, Calogaya decipiens, Peltula euploca* and *Peltula tortuosa*
5	Dry exposed rocks	*Caloplaca tropica, Calogaya decipiens, Caloplaca cupulifera, Peltula tortuosa* and *Buellia disjecta*
6	Siliceous exposed rocks	*Chrysopsora sp., Dimelaena thysanota, Diploschistes gypsaceus, Dirinaria consimilis* and *Rinodina oxydata*
7	Granite/ quartzite rocks	*Buellia disjecta, Caloplaca tropica* and *Megaspora subpoliotera,*
8	Acidic rocks	*Neobrownliella cinnabarina*
9	Exposed bauxite	*Endocarpon nanum, Endocarpon rosettum, Peltula euploca* and *Phylliscum testudineum*
10	Exposed rocks/boulders vertically or horizontally in rock shelters	*Peltula tortuosa, Endocarpon rosettum* and *Peltula zahlbrucknerii*
11	Moist rocks together with mosses horizontally arrange	*Phaeophyscia hispidula*

Table 2: The list of lichen taxa, their secondary metabolites and biodeterioration property of Bhimbetka World Heritage Zone, Madhya Pradesh

S.N.	*Lichens taxa*	*Growth forms*	*Lichen substances*	*Remarks*
1	*Botryolepraria lesdainii*	Leprose	Triterpene	Moderate
2	*Buellia disjecta*	Crustose	Atranorin and unknown substance at Rf class 4	Moderate
3	*B. posthabita*	Crustose	Atranorin and unknown chemical at Rf class 3	Moderate
4	*Calogaya decipiens*	Crustose	Parietin, yellow-orange spot at Rf 6	Aggressive
5	*Caloplaca cupulifera*	Crustose	Parietin	Aggressive
6	*C. orissensis*	Crustose	Parietin and atranorin	Aggressive
7	*C. tropica*	Crustose	Parietin and olive spot at Rf 4	Aggressive

8	*Chrysopsorasp-1*	Crustose	No chemical	Moderate
9	*Chrysopsorasp-2*	Crustose	Gyrophoric acid	Moderate
10	*Collema texanum*	Foliose	No chemical	Bioprotective
11	*Dimelaena thysanota*	Crustose	Usnic acid and Unknown chemical at Rf class 3, 4	Aggressive
12	*Diploschistes caesioplumbeus*	Crustose	Lecanoric and diploschistic acid.	Aggressive
13	*D. gypsaceus*	Crustose	Lecanoric acid	Aggressive
14	*D. rampoddensis*	Crustose	Lecanoric acid.	Aggressive
15	*D. scruposus*	Crustose	Diploschistic and lecanoric acid	Aggressive
16	*Dirinaria aegialita*	Foliose	Divaricatic acid.	Moderate
17	*D. confluens*	Foliose	Divaricatic acid and atranorin.	Moderate
18	*D. consimilis*	Foliose	Atranorin and Sekikaic acids	Moderate
19	*Endocarpon nanum*	Squamulose	No chemical	Bioprotective
20	*E. pusillum*	Squamulose	No chemical	Bioprotective
21	*E. rosettum*	Squamulose	No chemical	Bioprotective
22	*E. subrosettum*	Squamulose	No chemical	Bioprotective
23	*Fulgogasparrea awasthii*	Crustose	Parietin and a pale greenish-blue spot at Rf class 4.	Aggressive
24	*Lepraria lobificans*	Leprose	Stictic acid	Bioprotective
25	*Megaspora subpoliotera*	Crustose	Atranorin and olive spot at Rf 4	Aggressive
26	*Neobrownliella cinnabarina*	Crustose	Parietin, Xanthorin, Parietinic acids	Aggressive
27	*Parmotrema praesorediosum*	Foliose	Atranorin in traces and fatty acid at Rf class 3	Bioprotective
28	*Peltula euploca*	Squamulose	No chemical	Bioprotective
29	*P. obscurans*	Squamulose	No chemical	Bioprotective
30	*P. patellata*	Squamulose	No chemical	Bioprotective
31	*P. tortuosa*	Squamulose	No chemical	Bioprotective
32	*P. zahlbrucknerii*	Squamulose	No chemical	Bioprotective
33	*Phaeophyscia hispidula*	Foliose	Zeorin	Moderate
34	*Phylliscum indicum*	Crustose	No chemical	Bioprotective
35	*P. testudineum*	Crustose	No chemical	Bioprotective
36	*Physcia dilatata*	Foliose	Atranorin and zeorin	Moderate
37	*P. dimidiata*	Foliose	Atranorin	Moderate
38	*Pyxine petricola*	Foliose	Lichenoxanthone at Rf class 4 and a triterpene at Rf class 5	Moderate
39	*Rinodina oxydata*	Crustose	Atranorin	Moderate
40	*Staurothele fissa*	Crustose	No chemical	Bioprotective

thick forest cover which surrounds the rock shelters includes trees of *Mitragyna parvifolia, Terminalia alata, Careya arborea, Sterculia urens, Ficus mollis* and *Diospyros melanoxylon.*

The lichens communities of different substrata in British Isles have been extensively surveyed (James *et al.,* 1997). On hard limestone several distinct lichen communities were observed, most of which also grow on soft calcareous rocks. On calcareous tombstone at Cobham Churchyard, Surry, *Bueilla, Caloplaca*, *Lecanora* and *Physcia* have been reported as predominant species.

The lichen communities growing on rocks undergo regular patterns of successional change, one assemblage of species of many occupy a given rock surface for several years, steadily altering the substratum in ways that eventually better accommodate a new combination of species. Thus, over the time changing lichen communities relentlessly changes the rock surface. Brief description of each species under different lichens communities is provided with their habitat.

Ecology of the Lichen Communities

The Bhimbetika rock shelter area is situated on a flat hillock. The rock shelter area has good growth of semi shaded tree all around the rock shelters. Based on the different type of lichen species present on various habitats the Bhimbetka rock shelter

area following niches for colonization of lichens. Overall analysis of the results showed that colonization of species/communities was fairly uniform as several of the species were commonly present on many of the substrates.

Most of the communities prefers to grow on sandstones both in exposed and shaded rocks while siliceous, acidic, granite and bauxite dry exposed rocks bear only Teloshcistacean and Physcioid communities. The pore spaces in the sandstone are large enough to accommodate lichens and may partially account for abundance of lichens on the sandstone rocks. The swelling action of organic salts produced by lichens together with fracturing and incorporation of mineral fragments by lichen thalli are other ways of weathering. The rock shelters exhibit colonization by a variety of nitrophytic lichen taxa such as *Caloplaca*, *Lecanora* and *Verucarria* in exposed habitats (Singh & Shina 1993).

The growth and distribution of species is strongly influenced by the providing microclimatic parameters. The rocks subjected to direct irradiation showed colonization of crustose species strongly pigmented with dark brown-black or deep yellow to orange-red colour (species of crustose thalli *Caloplaca* and *Buellia*) while in shelter environments such as entrance of the cave large area of the wall are coated with *Lepraria*.

The lichens exhibit a close relationship with microclimatic factors thus can be used microclimatic monitoring of monuments. Most of the lichens particularly, cyanolichens (Cyanobacteria contacting photobiont) act as cloth to protect the exposed rock from high temperature, rains providing bioprotetion to the substrate (Bajpai *et al.,* 2012).

Enumeration of the Species

Crustose and squamulose community

Buellia disjecta Zahlbr.

The species is characterized by crustose-areolate thallus in centre and slightly lobate margin at periphery. The species grows on sandstone, quartz semi-shaded areas (Bajpai, 2007).

Chemistry: Thallus K+ yellow, C -, KC -, P-: atranorin and unknown substance at Rf class 4.

Biodeterioration activity: Moderate

Buellia posthabita (Nyl.) Zahlbr**.**

Fig.1 : Aggressive lichen species (A-B), Moderant lichen species (C-D), Bioprotective lichen species (E-F)
A. *Megaspora subpoliotera* **B.** *Neobrownliella cinnabarina* **C.** *Dirinaria confluens* **D.** *Physcia dilatata* **E.** *Endocarpon rosettum* **F.** *Parmotrema praesorediosum*

The species is characterized by brownish-yellow, cracked-areolate thallus with black innate to slightly emergent apothecia with mischoblastiomorphic spores. The species grows on sandstone, quartz semi-shaded areas (Bajpai, 2007).

Chemistry: Thallus K+ yellowish, C -, KC -, P-: atranorin and unknown chemical at Rf class 3.

Biodeterioration activity: Moderate

Chrysopsora sp-1

This species is characterized by yellowish-brown, crustose to squamulose thallus, marginally attached apothecia. The species grows on exposed siliceous rocks individually in association with thick black algal mass (Bajpai, 2007)

Chemistry: Thallus K -, C -, KC -, P-: No chemical present.

Biodeterioration activity: Moderate

Chrysopsora sp-2

The species is characterized by crustose areolate to squamulose, squamuliform thallus with upturned margin in centre to flat adpressed lobes marginally. It grows in association of *Peltula euploca* and *P. obscurans* on exposed siliceous rocks (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC+, P-: Gyrophoric acid.

Biodeterioration activity: Moderate

Dimelaena thysanota (Tuck.) Hale & W. L. Culb.

The species is characterized by radiate plicate, crustose thallus with cryptolecanorine apothecia. It grows abundantly on siliceous rocks (Bajpai, 2007).

Chemistry: Thallus K+ yellowish, KC+ yellowish, C -, P-: Usnic acid and Unknown chemical at Rf class 3, 4.

Biodeterioration activity: Aggressive

Diploschistes caesioplumbeus (Nyl.) Vain.

The species is characterized by areolate, grey to dark grey smooth, crustose thallus with peritheciod ascomata. It grows on siliceous rocks in exposed area in association with *Caloplaca* and *Peltula* (Bajpai, 2007).

Chemistry: Thallus K -, C+ red, KC -, P-: Lecanoric and diploschistic acid.

Biodeterioration activity: Aggressive

Diploschistes gypsaceus (Ach.) Zahlbr**.**

The species is characterized by whitish, pruinose, crustose thallus with lecanoric acid. It grows in shady places in association with other *Diploschistes* species and *Caloplaca* (Bajpai, 2007).

Chemistry: Thallus UV -, K -, C+red, KC -, P-: Lecanoric acid.

Biodeterioration activity: Aggressive

Diploschistes rampoddensis (Nyl.) Zahlbr.

The species is characterized by verrucose thallus, apothecioid ascomata and 18-24 × 6-11 um sized ascospores. It grows on siliceous rocks in open and shady places together with *Peltula* and *Endocarpon* species (Bajpai, 2007).

Chemistry: Thallus K -, C+ red, KC -, P-: Lecanoric acid.

Biodeterioration activity: Aggressive

Diploschistes scruposus (Schreb.) Norman.

The species is distinguished by verrucose thallus with apothecioid ascomata and presence of lecanoric and diploschistic acid. It grows in association with other *Diploschistes* species both in exposed and shady places on sandstone rocks (Bajpai, 2007).

Chemistry: Thallus K -, C+ red, KC -, P-: Diploschistic and lecanoric acid.

Biodeterioration activity: Aggressive

Endocarpon nanum Ajay Singh & Upreti

E. nanum is characterized by scattered, adnate, 1-caprous thallus having large and small squamules with pale under side; thick, black rimmed ostiole protruding out prominently from the thalline surface. It grows on rocks and cement plaster in shady and exposed sites in association with other species of *Endocarpon* and *Peltula* (Awasthi, 1997).

Chemistry: Thallus K -, KC -, C -, P-: No chemical substance

Biodeterioration activity: Bioprotective

Endocarpon pusillum Hedwig

The species is characterized by scattered, irregular brownish green squamules with 1-2 perithecia. It grows in exposed vertical slopes of present monument together with other species of *Endocarpon* and sometimes with Lichinaceae members such as *Phylliscum* (Awasthi, 1997).

Chemistry: Thallus K -, KC -, C -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Endocarpon rosettum Ajay Singh & Upreti **Fig.1E**

This species is distinguished in having rosette forming, large squamulose thallus with imbricate margins and squamules bearing numerous perithecia. It prefers to grow on horizontal surface, mostly in association with *Peltula euploca* and *Phylliscum indicum* (Bajpai, 2007)

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Endocarpon subrosettum Ajay Singh & Upreti

This species is characterized by squamulose, imbricate, ± adnate, rounded to irregular olive brown green, rosette forming up to 15 punctuate perithecia. It grows abundantly on the rocks both in exposed and sheltered areas. The species grows in large extensive patches in association with *Peltula*, *Phylliscum* and other *Endocarpon* species (Bajpai, 2007).

Chemistry: Thallus K -, KC -, C -, P-: No chemical substance

Biodeterioration activity: Bioprotective

Peltula euploca (Ach.) Poelt

This species is characterized by squamulose, umbilicate, marginally sorediate, peltate thallus. *P. euploca* is one of the most common species of lichen found growing on both vertical and horizontal rocks in exposed and shady areas in association with *Endocarpon*, *Phylliscum* and *Verrucaria* (Bajpai, 2007)

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Peltula obscurans (Nyl.) Gyelink

This species is distinguished by greenish grey, rounded to irregular, rosette shaped squamules with umbilicus on the lower side. It grows on fully exposed bauxite, sandstone rocks in association with the members of the lichen genera *Caloplaca*, *Endocarpon* and *Phylliscum* (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance present.

Biodeterioration activity: Bioprotective

Peltula patellata (Bagl.) Swinscow & Krog

This species is characterized by its orbicular to angulate or lobulate thallus, squamules with ascending margin and reticulate rugose upper surface. It prefers to grow on dry exposed rocks. The species grows mostly on horizontal plane in association with mosses on both cement plaster and bricks (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance

Biodeterioration activity: Bioprotective

Peltula tortuosa (Nées) Wetmore

The species is distinguished by subfruticose, erect, olive to brownish black squamules, flat at top. It grows on exposed, dry rocks arranged vertically or horizontally in association with other *Peltula* species and *Endocarpon* (Bajpai, 2007).

Chemistry: Thallus K -, KC -, C -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Peltula zahlbrucknerii (Hasse) Wetmore

This species is characterized by squamulose thallus, inflated, minutely lobed greenish grey squamules. It grows on dry exposed rocks in Jamunjhiri and Rang Mahal area of the Bhimbetka rock shelters (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Phylliscum indicum Upreti

The species is characterized by squamulose thallus, dark brown to black compactly aggregated squamules with umbilicus on the lower side. It is one of the most common species of the area found growing both on exposed, shady rocks on horizontal and vertical slopes mostly with *Endocarpon* and *Peltula* species (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Phylliscum testudineum Henssen

This species is distinguished by its squamulose thallus, dark black, compactly aggregated lobules attached centrally by short umbilicus. It is rare in the area, as known from a single locality on exposed rocks growing in association with *Peltula* and *Endocarpon* species (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance.

Biodeterioration activity: Bioprotective

Staurothele fissa (Taylor) Zwackh

The species is characterized by greenish-areolate, perithecia bearing crustose thallus. It grows in moist open areas on siliceous rocks in association with *Endocarpon, Peltula* and *Caloplaca* species (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical substance present

Biodeterioration activity: Bioprotective

Teloschistacean community

Calogaya decipiens (Arnold***)*** Arup, Frödén & Sochting

The species is characterized by thin, yellowish-orange crustose thallus with crateriform soralia, growing in association with *Peltula* species on sandstone (Mishra *et al*., 2020)

Chemistry: Thallus K+ purple, C -, KC -, P-: Parietin, yellow-orange spot at Rf 6.

Biodeterioration activity: Aggressive

Caloplaca cupulifera (Vain) Zahlbr.

The species is characterized by thin, yellowish-orange crustose thallus with crateriform soralia. The species is found growing over non calcareous rocks, both in exposed and shaded locations in association with *Endocarpon* and *Peltula* species (Mishra *et al*., 2020)

Chemistry: Thallus K+ purple, C -, KC -, P -: Parietin present.

Biodeterioration activity: Aggressive

Caloplaca orissensis (Räsänen) D.D. Awasthi

The species is characterized by the rimose-areolate to verrucose, whitish or whitish-grey, crustose thallus, apothecia biatorine, round, 0.3- 0.6 mm diam., disc dark brown to black; 8-spored asci, polaribilocular, ellipsoid to ovoid, 8.0-9.0 × 6.5-7.0 µm ascospores. The species is found growing over sun exposed sandstone (Awasthi, 1997).

Chemistry: Thallus K+ yellow, C -, Pd -; Medulla K-, C -, Pd -. Apothecial disc K- but epihymenium K+ purple.TLC: Parietin and atranorin.

Biodeterioration activity: Aggressive

Caloplaca tropica Y. Joshi & Upreti

The species is characterized by an indistinct grey, crustose thallus, orange to orange-brown apothecial discs with prominent black proper margin and narrowly ellipsoid spores with narrow septa. The species is found growing over sun exposed quartzite rocks in association with *C. aloplaca*, *C. poliotera*, *C. orissensis* and *Buellia* species in more or less dry areas (Mishra *et al*., 2020)

Chemistry: Thallus K -, C -, KC -, P-: Parietin and olive spot at Rf 4.

Biodeterioration activity: Aggressive

Fulgogasparrea awasthii (Y. Joshi & Upreti) S.Y. Kondr., Upreti & A. Thell

The species is characterized by effigurate to ± subsquamulose yellow-orange to orange-red, crustose thallus with blastidia. This species is preferring to grow on exposed rocky substances (Mishra *et al*., 2020).

Chemistry: Thallus K+ purple, C -, KC -, P-: Parietin and a pale greenish-blue spot at Rf class 4.

Biodeterioration activity: Aggressive

Megaspora subpoliotera (Y. Joshi & Upreti) S.Y. Kondr., Upreti & A. Thell, **Fig.1A**

The species is characterized by a rimose-areolate grey coloured, crustose thallus with whitish soredia, orange-red apothecial disc and a black proper margin. The species is found growing over exposed quartzite, granite and non-calcareous rocks in association with *Peltula euploca*, *C. aloplaca* and *C. subsoluta* species (Mishra *et al.,* 2020).

Chemistry: Thallus K+ yellow, KC -, C -, P-: Atranorin and olive spot at Rf 4.

Biodeterioration activity: Aggressive

Neobrownliella cinnabarina (Ach.) S.Y. Kondr., Upreti & A. Thell **Fig.1B**

The species is characterized by reddish orange to orange cracked areolate, crustose thallus in centre and slightly elongated thallus at margin, which delimited abruptly. It grows on acidic rocks mostly isolated (Mishra *et al*., 2020).

Chemistry: Thallus K+ purple, C -, KC -, P-: Parietin, Xanthorin, Parietinic acids.

Biodeterioration activity: Aggressive

Cyanophycean community

Collema texanum Tuck.

A foliose lichen characterized in having isidiate and olivaeous green, foliose thallus. It prefers to grow on moist shady sandstone places at the study area (Awasthi, 2007).

Chemistry: Thallus K -, C -, KC -, P-: No chemical present.

Biodeterioration activity: Bioprotective

Physcioid community

Dirinaria aegialita (Afzel) B. J. Moore

The species is easily distinguished by foliose thallus, irregularly thickened, simple to coralloid, branched, isidia producing coarse granular soredia. It grows on smooth rocks in shady moist places in association with *Buellia* and *Caloplaca* species (Bajpai, 2007).

Chemistry: Thallus K+ yellow, KC -, C -, P-: Divaricatic acid.

Biodeterioration activity: Moderate

Dirinaria confluens (Fr.) D.D. Awasthi **Fig.1C**

The species is characterized by glaucous grey, appressed to agglutinate, pinnately lobate, foliose thallus, and presence of divarciatic acid. It grows on more or less smooth siliceous rocks in moist shady places in association with *Caloplaca* and *Buellia* species (Awasthi 2007).

Chemistry: Thallus K+ yellow, C -, KC -, P+ yellow: Divaricatic acid and atranorin.

Biodeterioration activity: Moderate

Dirinaria consimilis (Stirt.) D.D. Awasthi

The species is distinguished by sorediate, foliose thallus, with farinose soredia on verrucal growth. It grows on semi-shaded rocks mostly on smooth surface rocks in association with *Buellia*, *Parmotrema sp*. and *Peltula* species (Awasthi, 2007).

Chemistry: Thallus K+ yellow, C -, KC -, P-: Atranorin and Sekikaic acids.

Biodeterioration activity: Moderate

Phaeophyscia hispidula (Ach.) Essl.

P. hispidula is characterized by foliose thallus, rhizines projecting beyond the margins and soralia laminal, pustulate, becoming ± capitate. In the study area it grows on moist rocks mostly horizontal rocks together with mosses or in association with *Lepraria* species. This species is recognized as poleotolerent lichen species (Awasthi, 2007).

Chemistry: Thallus K -, C -, KC -, P-: Zeorin in traces.

Biodeterioration activity: Moderate

Physcia dilatata Nyl.

The species is characterized by imbricate, sinuate lobate, farinose, foliose thallus. It grows in semi-shaded, smooth rocks in association with *Pyxine*, *Physcia* and *Parmotrema* species (Bajpai, 2007).

Chemistry: Thallus K+ yellow, C -, KC -, P-: Atranorin and zeorin.

Biodeterioration activity: Moderate

Physcia dimidiata (Arn.) Nyl.

This species is characterized by whitish, pruinose, sorediate, foliose thallus. It grows on semishaded rocks having smooth surface in association with *Dirinaria*, *Buellia*, *Pyxine* and *Parmotrema* species (Bajpai, 2007).

Chemistry: Thallus K+ yellow, C -, KC -, P-: Atranorin.

Biodeterioration activity: Moderate

Pyxine petricola Nyl.

This species is characterized by whitish grey, closely appressed lobate, foliose thallus with plaques of pruina on the upper surface. It grows on semi-shaded smooth surface rocks in horizontal walls with *Physcia*, *Caloplaca*, *Diploschistes* and *Buellia* species (Bajpai, 2007).

Chemistry: Thallus K -, C -, KC -, P- Lichenoxanthone at Rf class 4 and a triterpene at Rf class 5.

Biodeterioration activity: Moderate

Rinodina oxydata (A. Massal.) A. Massal.

This species is characterized by rimose areolate, crustose thallus with lecanorine margin and brown-black disc of apothecia. It grows on siliceous rocks, in association with species of *Caloplaca* and *Buellia* species (Bajpai, 2007).

Chemistry: Thallus K+yellow, C -, KC -, P-: Atranorin.

Biodeterioration activity: Moderate

Leprarioid community

Botryolepraria lesdainii (Hue) TCanals.

The species is characterized by leprose, granular thallus with no differentiation of layers. It grows in shady and damp places mostly on the vertical walls near passage of rock shelters (Bajpai, 2007)

Chemistry: Thallus K -, C -, KC -, P- unidentified triterpene at Rf class 5.

Biodeterioration activity: Moderate

Lepraria lobificans Nyl.

The species is characterized by leprose (powdery) thallus with dense mass of soredia. It is one of the most common lichen in shady moist places, growing is association with members of cyanophycean lichens (Awasthi, 2007).

Chemistry: Thallus K+ red, C -, KC -, P-: Stictic acid complex.

Biodeterioration activity: Bioprotective

Parmelioid community

Parmotrema praesorediosum (Nyl.) Hale **Fig.1F**

P. praesorediosum is characterized by the adnate, coriaceous, foliose thallus, eciliate lobes with ascending sorediate margins. The taxon is common on exposed rock surface and on rocks under semi-shaded trees in association with *Lepraria lobificans* (Mishra & Upreti, 2018).

Chemistry: Thallus K -, C -, KC -, P- and cortex K+ yellow: Atranorin in traces and fatty acid at Rf class 3.

Biodeterioration activity: Bioprotective

From the above inventory of lichens growing on rock shelters of Bhimbetka it is evident that the crustose, squamulose lichens producing secondary metabolites, though devoid of rhizine, but attached with their whole lower surface and hyphal threads penetrate the substrate and deteriorate it physically and chemically. The crustose squamulose members of cyanobacteria containing lichens also attached tightly to the substrate mostly devoid of chelating substances and not involved in geochemical deterioration. The agglutinated nature of thalli though involves in geophysical deterioration but also act as a cloth and play a role as bioprotective agent.

Conclusion

The study will provide a general assessment of the nature of the lichen evolved in geochemical or geophysical weathering together with extent to which micro-environments and possible changes in the environment may influence the growth of lichens. Periodic monitoring of both aggressive and bioprotective lichen communities will not only provide an important information regarding the current status of the rock shelters but also useful for the conservators to adopt appropriate management strategies for conservation.

Acknowledgment

Authors are thankful to the Director, CSIR-National Botanical Research Institute, Lucknow for providing the necessary laboratory facilities. (OLP-101)

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