REVIEW ARTICLE

Role of Lichen Extracts as a Potential Source of Natural Fungicides

Rashmi S[1*], Rajkumar H G[2]

[1]Department of Biotechnology, Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Karnataka, India.

[2]Department of studies in Botany, Manasagangotri, University of Mysore, Karnataka, India.

Received: 20th February, 2024; Revised: 27th March, 2024; Accepted: 15th August, 2024; Available Online: 25th September, 2024

ABSTRACT

Plant pathogens and the diseases they cause are major to humanity. Each year, we lose more than thirty percent of crops worldwide to bacterial and fungal diseases. Lichen is a composite organism made up of two unrelated species: algae and fungi. These two components live together and behave as a single organism. When two organisms live together in this way, they provide mutual benefits to one another. They are referred to as symbionts. Lichens produce many rare secondary products not found in other plants. The uniqueness of many aromatic products sparked early chemical interest in lichen compounds. Lichens are an underutilized source of industrially important as it proven many biological activities, and yet there is much more to study about their efficacy. Lichen bioactive metabolites showed promising use in biopharmaceutical applications and for the preparation of new formulations or innovations to support human life. This review aims to summarize the research and development trends from the past and present in the bioactive fungicides against plant pathogens.

Keywords: Plant pathogens, Fungicides, Lichens, Secondary metabolites

International Journal of Drug Delivery Technology (2024); DOI: 10.25258/ijddt.14.3.82

How to cite this article: Rashmi S, Rajkumar HG. Role of Lichen Extracts as a Potential Source of Natural Fungicides. International Journal of Drug Delivery Technology. 2024;14(3):1836-1841.

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Among all the microorganisms that cause plant diseases, fungi are proven to be the most devastating microorganisms that are responsible for a decrease in food quality and will also reduce the total yield of the crops. To reduce the disease severity and to prevent the diseases caused by plant pathogenic fungi, mostly commercially available fungicides are used. Fungicides are chemicals used to prevent or cure fungal diseases that negatively affect plant health, yield, and product quality.[1] The frequency of fungal diseases is increasing in various crop plants due to climatic conditions, the use of high-yielding varieties, and the lack of awareness among farmers. Currently, about 80% of the crops that have been grown in the United States are coated at least one or more fungicides per season, if those crops are not pre-treated, then yields would decrease by 50 to 95%.[2] Fungicide use in India is quite low compared to developed countries. The consumption of fungicides in 2009 was 8307 MT compared to other pesticides.[3]

Many fungicides persist in soil for decades. Chemically prepared fungicides are not degradable. They get mixed with surface water and also get drained into underground water, hence causing significant contamination of the environment. It might be air, water, or soil. Based on the strong chemical properties of fungicides, they can penetrate deep into the tissues, accumulate in food chains, and consequently impact the environment.[4] The use of many fungicides is restricted due to problems where most of the pathogens have developed resistance to those fungicides. It is toxic to all forms of living organisms and re-emergence of disesase.[5] At present, these chemicals are present in the biosphere as ubiquitous pollutants and on non-enveloped organisms in our urban environments, where they can have a detrimental effect on all living organisms. It is now widely accepted that certain chemicals present a risk to human health and other life forms, as well as undesirable effects on the environment.[6] These chemical agents have several disadvantages; expensive, residual content will be found in the environment, which causes toxicity to living organisms, and the emergence of resistant capacity towards the pathogens.

Therefore, scientists have been actively looking for fungicides that exhibit less toxicity, more selectivity, and strong action against fungal strains.[7] The alternative to using these chemicals is to use natural products to inhibit plant diseases. Biopesticides are usually microbial biological control agents used similarly to chemical pesticides. The biggest advantage of biopesticides is that they don't have harmful residues. If the biopesticides are produced locally it can be much cheaper to mankind. Biopesticides can be more effective in the irradiation

*Author for Correspondence: s.rashmi@manipal.edu

of pathogens when compared to chemical fungicides, and most importantly, they are biodegradable in nature.[8]

Lichens are one such natural product that could be used as a fungicide. They are unique in nature and physiology in that they look and behave quite differently from the organisms that surround them. Lichens are ubiquitously distributed organisms found in various climatic conditions from tropical regions to polar regions and are an important component of terrestrial biodiversity. Lichen thallus contains bioactive substances that exhibit a diverse range of biological activities. Lichen substances show excellent antibacterial and antifungal properties and this makes them potential candidates for substituting antibiotics. Bioactive substances from lichens have provided a wide range of therapeutic benefits.[9]

More than 50% of known lichen species have proved to have therapeutic values. The bioactive nature of secondary lichen constituents suggests possible strategies for controlling plant pathogens, which may include influencing various developmental stages, such as preventing spore germination and inhibiting sexual reproduction or directly affecting mycelial growth. These strategies may be achievable by applying a purified bioactive compound or a series of components with synergistic effects.[10] Another unique feature of lichens is the development of their secondary metabolites, which are not found in any plant kingdom. According to their chemical structures, most lichen substances are phenolic compounds, dibenzofurans, depsides, depsidones, depsones, lactones, quinones, pulvinic acid derivatives which are structurally identified as orcinol and b-orcinol derivatives, usnic acid, barbatic acid, salazinic acid, picrolichenic acid, protolichesterinic acid and nephrosterinic acid, parietin, vulpinic acid respectively.[11-13] Despite lichens having shown great potential towards biological activities, it has been neglected by mycologists and the pharmaceutical industry.[14] The results of the study call for further investigation into the emergence of novel antifungal molecules within the lichen ecosystem.

RESULTS AND DISCUSSION

Most of the studies are based on comparing the antifungal capabilities of crude lichen extracts (Table 1); as a result, the need to investigate for the active metabolic properties of purified lichen against plant-infecting fungal pathogens was emerging[15]. Lichen compounds are generated based on the harsh environmental conditions so that they can resist the changes that occur in their surroundings.[16]

Effect of Bioactive Compounds from Lichen

Studies have shown that lichen secondary metabolites range from 700 to 1050[17] and they are unique to lichens. Among them, approximately 10% of secondary metabolites are found in mycobionts.[18] In lichen thallus, secondary metabolites are produced by fungus alone in the form of the crystals.[19] Screening of lichen extracts has revealed the efficacy of secondary metabolites towards antibiotic, antimycobacterial, antiviral, antitumor, analgesic, and antipyretic properties.[20] A meta-analysis of information on the analysis of lichen extracts against different variants of *Fusarium* spp was studied. Lichen samples were extracted from 51 corticolous, 17 terricolous and 18 saxicolous lichen species, from which 37 secondary compounds were tested against 8 fungal species, like *Fusarium acuminatum, F. avenaceum, F. culmorum, F. fujikuroi, F. oxysporum, F. roseum, F. solani* and *F. udum.*[21] Extracts obtained from lichens such as *Protousnea poeppigii* and *Usnea florida* tested against different pathogenic fungi, with isodivaricatic acid, 5-propyl resorcinol, divaricatinic acid and usnic acid identified as antifungal agents,[22,23] while the lichen *Parmelia reticulate*, along with its metabolites protolichesterinic acid and atranorin, were active against soilborne pathogenic fungi.[24]

Advantages of Natural Fungicides

Several lichens have fungicidal potential, and numerous studies have shown effectiveness against pathogenic microorganisms[25]. The role of fungicides in the inhibition of pathogens is as follows: Inhibit spore germination, suppress mycelial growth, delay sporulation, reduce pathogenicity, reduce incidence and severity.[26]

For natural fungicides to meet consumer standards, there must be sufficient data and information about the structure and efficiency of secondary metabolites. Major benefits to farmers from integration of natural products in agricultural production systems could lower the severity of plant diseases can produce high-quality crops that fetch great prices. Consumers create the demand in markets for natural fungicides derived from lichens in markets where they are willing to pay higher prices for organic foods.[27]

Since it has become noticeable that natural fungicides have an impact on motivating the production of modern agrochemical research, demand for lichen-derived products can be increased. The development of natural fungicides would contribute to the reduction of the negative effects of synthetic agents, which could contaminate the environment by its residues.[28]

Challenges in Adopting Natural Metabolites for Commercialization

Lichens are becoming increasingly commercialized in the future, using biotechnological approaches can substitute the limited availability of secondary compounds that are physiologically active, commercially valuable, and medicinally significant. Right now, several secondary metabolites with diverse structures have reportedly exhibited various antifungal properties. While the current market share of commercialized natural fungicides is very constrained, by intensive research on this topic many new products can be developed. Lichen-derived fungicidal compounds exhibit relatively less toxicity and increase the likelihood of the development of natural fungicides. Thus metabolites obtained from lichens would be a vital source for the control of plant disease.[29]

Table 1: Screening of crude extracts and antifungal activities

S. No	*Name of the lichen*	*Controlled plant pathogen*	*Source*
1	Stereocaulon ramulosum	Aspergillus fumigatus, A. niger, Cladosporium resinac, Fusarium oxysporum, Verticillium dahliae	30
2	*Evernia prunastri*, *Hypogymnia physodes* and *Cladonia portentosa*	*Pythium ultimum*, *Phytophthora infestans*, *Rhizoctonia solani*, *Botrytis cinerea*, *Colletotrichum lindemuthianum*, *Fusarium solani*, *Stagonospora nodorum, Ustilago maydis*	31
3	*Hypogymnia physodes, Ramalina farinacea*	*Aspergillus flavus*	32
4	*Cladonia scabriuscula*, *Melanelia* sp., *Nephromopsis asahinae*, *Nephromopsis pallescens, Parmelia laevior*, *Pertusaria* sp., *Ramalina conduplicans*, *R. sinensis*, *Ramalin* sp., *Umbilicaria proboscidea, Vulpicida* sp.	*Botryosphaeria dothidea*, *Botrytis cinerea*, *Diaporthe actinidiae*, *Pestalotiopsis longiseta*, *Pythium* sp., *Rhizoctonia solani, Sclerotium cepivorum*	33
5	*Cladonia furcata, Parmelia caperata, P. pertusa, Hypogymnia physodes, Umbilicaria polyphylla*	*Aspergillus flavus, A. fumigatus, Botrytis cinerea, Fusarium oxysporum, Mucor mucedo, Paecilomyces variotii, Penicillium purpurescens, P. verrucosum*, *Trichoderma harsianum*	34
6	*Everniastrum cirrhatum*	*Aspergillus niger, A. fumigatus*	35
7	*Ramalina hossei*	*Aspergillus niger, A. fumigatus*	36
8	*Usnea longifolia*, *Cetraria* spp., *Parmotrema reticulatum, Evernastrium nepalense*	*Fusarium oxysporum, F. moniliforme, F. erdiforme, F. porliferatum, Exserhilium turticum*	37
9	*Parmelia reticulata*	*Sclerotium rolfsii, Rhizoctonia solani, R. bataticola, Fusarium udum, Pythium aphanidermatum, P debaryanum*	24
10	Bulbothrix set-schwanensis, Everniastrum nepalense, Heterodermia diademata, Parmelaria thomsonii	*Aspergillus flavus, A. fumigatus, Alternaria alternata, Fusarium oxysporum, F. solani, F. roseum, Penicillium citrinum*	38
11	*Lecanora atra*, *L. muralis, Parmelia saxatilis*, *P. sulcata, Parmeliopsis ambigua*	Aspergillus flavus, Fusarium oxysporum	39
12	Parmelia perlata	*Fusarium oxysporum, Rhizopus nigricans*	40
13	Heterodermia boryi, Sticta weigelia, Dermatocarpon vellereum	Phomopsis leptostromiformis var. occidentalis, Fusarium oxysporum	41
14	Caloplaca variabilis, Fulgensia subbracteata, Lecanora muralis, Physcia adscendens	Fusarium moniliforme, Verticillium dahlia	42
15	Parmotrema tinctorum, P. Grayanum, P. praesorediosum	Colletotrichum capsica	43
16	Flavoparmelia caperata	Aspergillus niger, A. flavus, Fusarium oxysporum, F. solani, Colletotrichum falcatum	44
17	Parmotrema reticulatum	Aspergillus niger, A. flavus, Fusarium oxysporum, Fusarium solani, Colletotrichum falcatum	45
18	Flavoparmelia caperata, Roccella montagnei, Teloschistes flavicans, Physcia aipolia, Parmotrema austrosinensis, P. grayanum, P. tinctorum, P. reticulatum, Usnea sp., Sticta sp	Fusarium oxysporum	46
19	*Everniastrum cirrhatum*	*Fusarium oxysporum, F. udum*	47
20	Parmotrema perlatum	Aspergillus niger	48
21	*Acarospora strigata*, *Collema crispum*, *Placidium squamulosum*, *Physcia biziana*, *Lecanora prophetae-eliae, Ramalina farinacea*	*Fusarium moniliforme, Verticillium dahlia*	49
22	Heterodermia leucomelos	Aspergillus niger, A. flavus, Fusarium oxysporum, F. solani, Colletotrichum falcatum	50
23	*Evernia prunastri, Pseudevernia furfuracea* var. *furfuracea, Parmelia sulcata*	*Aspergillus niger, Botrytis cinerea, Fusarium culmorum, F. solani, Macrophomina phaseolina, Penicillium expansum, Rhizoctonia solani*	51
24	Flavoparmelia caperata, Parmotrema austrosinensis, P. grayanum, P. reticulatum, P. tinctorum, Physcia aipolia, Roccella montagnei, Teloschistes flavicans	Fusarium solani	52

25	Heterodermia leucomela, Flavoparmelia caperata, Pseudocyphelaria aurata, P. tinctorum, Parmotrema austrosinensis	Macrophomina phaseolina	53
26	*Ramalina capitaat*, *Xanthoparmelia stenophylla*, *Umbilicaria cylindrical*, *Rhizoplaca crysoleuca, Anamylopsora pulcherrima*	*Fusarium oxysporum, Ralstonia solanacearum*	54
27	*Xanthoria parietina*	*Aspergillus niger, A. oryzae, Rhizopus spp., Acromonium chrysogenum, Trichoderma harzanium*	55
28	*Ramalina hossei, Ramalina conduplicans*, *R. pacifica*	*Alternaria* sp., *Curvularia* sp., *Fusarium* sp.	56
29	*Stereocaulon alpinum*, *Sphaerophorus globosus*	*Alternaria mali, Cochliobolus miyabeanus, Colletotrium gloeosporioide, Verticillum dahliae*	57
30	*Usnea longissimia*, *Cetrelia braunsiana*	*Aspergillus niger, Fusarium oxysporum*	**58**
31	Parmotrema andium, Dirinaria applanata	*Aspergillus niger*, *Penicillium verrucosum, Fusarium oxysporum*	59
32	*Cetraria islandica, Cladonia mitis, C. rangiferina, Pseudevernia furfuracea, Usnea dasopoga*	*Fusarium oxysporum*, *F. avenacuem*	60
33	Thamnolia vermicularis	Alternaria alternata, A. mali, Colletotrichum gloeosporioides, Diaporthe actinidiae, Fusarium oxysporum f. sp. lycopersici, Pythium ultimum, Rhizoctonia cerealis, Rhizoctonia solani, Sclerotinia sclerotiorum, Botrytis cinerea, Botryosphaeria dothidea	61
34	Usnea longissima	Fusarium graminearum	62
35	Parmotrema austrosinense	*Hypoxylon serpens, Macrophoma theicola*, *Phomopsis theae, Tunstallia aculeate, Cercospora theae, Glomerella cingulate*, *Pestalotiopsis theae, Poria hypolateritia*	15
36	*Trypethelslium virens, Phaeographis dendritica*	*Aspergillus niger, Botrytis cinerea*, *Penicillium verrucosum*	63
37	*Caloplaca flavescens, Diploicia canescens, Cladonia fimbriata, Psilolechia lucida, Lecanora campestris, Pertusaria amara f. amara, Lecanora sulphurea, Porpidia tuberculosa, Lepraria incana, Xanthoria calcicola*	*Aspergillus flavus*	64

CONCLUSION

Lichens are an essential reservoir of natural biochemical agents that have received less attention and have not been investigated thoroughly. Based on the literature, researchers are increasingly prioritizing the exploration of novel metabolites that may be utilized for the eradication of diverse diseases, particularly organisms that cause plant diseases. In mere future, lichen extracts can be utilized to protect against fungal agents, with/or the extracts containing mixtures of other organic components. These studies prove that lichen can be used as a bio-fungicide to inhibit plant pathogenic fungi from causing severe disease to crop plants and may also enhance the yield and quality of crops.

REFERENCES

1. Rouabhi R. Introduction and Toxicology of Fungicides. InTech. doi: 10.5772/12967 2010.

2. Gianessi L, Reigner N. The importance of fungicides in U.S. crop production. Outlook Pest Management, 2006; 10: 209–213.
3. Thind TS. Fungicide Resistance in Crop Protection: Risk and Management. CABI, DOI 10.1079/9781845939052.0064. 2012.
4. Kumar S, Sharma AK, Rawat SS, Jain DK, Ghosh S. Use of pesticides in agriculture and livestock animals and its impact on environment of India. Asian Journal of Environmental Science, 2013; 8(1): 51-57.
5. Hurley PM, Hill RN, Whiting RJ. Mode of carcinogenic action of pesticides inducing thyroid follicular cell tumors in rodents. Environmental Health Perspectives, 1998; 106: 437–445.
6. Forget G, Goodman T, de Villiers A. Balancing the need for pesticides with the risk to human health. In: Impact of Pesticide Use on Health in Developing Countries. IDRC, Ottawa: 2, 1993.
7. Chen F, Han P, Liu P, Si N, Liu J, Liu X. Activity of the novel fungicide SYP-Z048 against plant pathogens. Scientific Reports, 2014; 4(1): 1-6.
8. Bhardwaj T and Sharma JP. Impact of pesticides application in the agricultural industry: An Indian scenario. International Journal of Agriculture and Food Science Technology, 2013; 4(8): 817-822.
9. Vartia KO. Antibiotics in lichens. In *The Lichens*; Elsevier: Amsterdam, The Netherlands, 1973; 547–561.
10. Kowalski M, Hausner G, Piercey-Normore MD. Bioactivity of secondary metabolites and thallus extracts from lichen fungi. Mycoscience, 52:413–418. DOI 10.1007/s10267-011-0118-3, 2011.
11. Culberson CF, Elix JA. Lichen substances. London: Academic Press; 1989.
12. Huneck S, Yoshimura I. Identification of lichen substances. New York, Springer- Verlag, Berlin, Heidelberg; 1996; 1- 492.
13. Shukla P, Upreti DK, Tiwari P. Assessment of dye yielding potential of Indian lichens. Indian Journal of Plant Sciences, 2014; 3(1): 57-63.

14. Ren M, Jiang S, Wang Y, Pan X, Pan F, Wei X. Discovery and excavation of lichen bioactive natural products. Front Microbiol. 2023; 17; 14:1177123.
15. Rajendran K, Ponmurugan P, Gnanamangai BM, Karuppiah P, Shaik MR, Khan M, Khan M, Shaik B. Bioefficacy of Lecanoric Acid produced by *Parmotrema austrosinense* (Zahlbr.) Hale against Tea Fungal Pathogens. Horticulturae, 2023; 9(705): 1-11.
16. Dayan FE, Romagni JG. Lichens as a potential source of pesticides. Pestic. Outlook, 2001; 12, 229–232.
17. Molnár K, Farkas E. Current results on biological activities of lichen secondary metabolites: a review. Zeitschrift für Naturforschung C; 2010; 65:157–173.
18. Nash TH. Lichen Biology. III (ed.), Cambridge University Press, Cambridge; 2008.
19. Ozturk S, Guvenc S, Arikan N, Yilmaz O. Effect of Usnic acid on mitotic index in root tips of Allium cepa L. Lagascalia, 1999; 21: 47-52.
20. Rankovic B, Misic M, Sukdolak S. Evaluation of antimicrobial activity of the lichens *Lasallia pustulata, Parmelia sulcata, Umbilicaria crustulosa* and *Umbilicaria cylindrical*. Microbiol., 2007; 76(6): 723-727.
21. Furmanek L, Czarnota P, Seaward MRD. A review of the potential of lichen substances as antifungal agents: the effects of extracts and lichen secondary metabolites on *Fusarium* fungi. Archives of Microbiology, 2022; 204:523 (1-31).
22. Schmeda-Hirschmann G, Tapia A, Lima B, Pertino M, Sortino M, Zacchino S, de Arias AR, Feresin GF. A new antifungal and antiprotozoal depside from the Andean lichen *Protousnea poeppigii*. Phytother Res, 2008; 22:349–355.
23. Basile A, Rigano D, Loppi S, Di Santi A, Nebbioso A, Sorbo S, Conte B, Paoli L, De Ruberto F, Molinari AM, Altucci L, Bontempo P. Antiproliferative, antibacterial and antifungal activity of the lichen *Xanthoria parietina* and its secondary metabolite parietin. Int J Mol Sci, 2015; 9-16(4):7861-75.
24. Goel M, Dureja P, Rani A, Uniyal PL, Laatsch H. Isolation, characterization and antifungal activity of major constituents of the Himalayan lichen *Parmelia reticulata.* Tayl. J Agric Food Chem, 2011; 59: 2299–2307.
25. Ngegba PM, Cui G, Khalid MZ, Zhong G. Use of Botanical Pesticides in Agriculture as an Alternative to Synthetic Pesticides. *Agriculture,* 2022; 12(5):600.
26. Khalid S, Nadeem A, Shaheen S, Mammadova R, Bakhsh A. Crop Protection for Sustainable Agriculture in the Era of Climate Change. In Climate- Resilient Agriculture, Springer, 2023; 1: 349-378.
27. Lengai GMW, Muthomi JW, Mbega ER. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. Scientific African, 2020; 7, 1-13.
28. Yoon MY, Cha B, Kim JC. Recent trends in studies on botanical fungicides in agriculture. Plant Pathol J, 2013; 29(1):1-9.
29. Deresa EM, Diriba TF. Phytochemicals as alternative fungicides for controlling plant diseases: A comprehensive review of their efficacy, commercial representatives, advantages, challenges for adoption, and possible solutions. Heliyon, 2023; 9:1-16.
30. Hickey BJ, Lumsden AJ, Cole AL, Walker JR. Antibiotic compounds from New Zealand plants: methyl haematommate, an antifungal agent from *Stereocaulon ramulosum*. New Zealand Natural Sciences, 1990; 17: 49-53.
31. Halama P, Haluwin CV. Antifungal activity of lichen extracts and lichenic acids. Biological Control, 2004; 49: 95–107.
32. Suberu H. Preliminary studies of inhibitions in *Aspergillus flavus* with extracts of two lichens and Bentex-T fungicide. African Journal of Biotechnology, 2004; 3(9): 468- 472.
33. Oh S, Jeon H, Lim K, Koh Y, Hur J. Antifungal activity of lichen forming fungi isolated from Korean and Chinese lichen species against plant pathogenic fungi. Plant Pathology Journal, 2006; 22(4): 381-385.
34. Ranković B, Mišić M, Sukdolak S. Antimicrobial activity of extracts of the lichens *Cladonia furcata, Parmelia caperata, Parmelia pertusa, Hypogymnia physodes* and *Umbilicaria polyphylla*. Biologia, 2009; 64(1): 53-58.
35. Swathi D, Suchitha Y, Prashith Kekuda PTR, Venugopal TM, Vinayaka KS, Raghavendra HL, Mallikarjun N. Antimicrobial, anthelmintic and insecticidal activity of a macrolichen *Everniastrum cirrhatum* (fr.) Hale. International Journal of Drug Development and Research, 2010; 2(4):780-789.
36. Kumar PSV, Kekuda TRP, Vinayaka KS, Swathi D, Mallikarjunand N, Nishanth BC. Studies on proximate composition, antifungal and anthelmintic activity of a macrolichen *Ramalina hossei* H. Magn & G. Awasthi. International Journal of Biotechnology and Biochemistry, 2010; 6(2): 191-201.
37. Baral B, Mahajan BL. Assessment of antimicrobial and phytochemical potentials of high altitudinal Nepalese lichens. Journal of Microbiology, Biotechnology and Food Sciences, 2011; 1(1): 98-112.
38. Tiwari P, Rai H, Upreti DK, Trivedi S, Shukla P. Assessment of antifungal activity of some Himalayan foliose lichens against plant pathogenic fungi. American Journal of Plant Sciences, 2011; 2: 841-846.
39. Ranković B, Kosanić M. Antimicrobial activities of different extracts of *Lecanora atra, Lecanora muralis, Parmelia saxatilis, Parmelia sulcata* and *Parmeliopsis ambigua*. Pakistan Journal of Botany, 2012; 44(1): 429-433.
40. Tippeswamy B, Sushma NR, Naveenkumar KJ. Antimicrobial property of bioactive factor isolated from *Parmelia perlata*. International Multidisciplinary Research Journal, 2012; 2(2):1-5.
41. Balasubramanian M, Nirmala P. Antimycobacterial activity of Foliose Lichens on Plant and Animal Pathogens. International Journal of Pharmaceutical Sciences and Research, 2014; 5(11): 4825-4831.
42. Valadbeigi T, Bahrami AM, Shaddel M. Antibacterial and Antifungal Activities of Different Lichens Extracts. J Med Microbiol Infec Dis, 2014; 2(2): 71-75.
43. Kekuda PTR, Vivek MN, Kambar Y, Manasa M. Biocontrol potential of *Parmotrema* species against *Colletotricum capsici* isolated from anthracnose of chilli. Journal of Biological and Scientific opinion, 2014; 2(2): 166-169.
44. Babiah PS, Upreti DK, John SA. Fungicidal efficacy of a foliose Lichen *Flavoparmelia caperata* (L.) Hale against phytopathogenic fungi. International Journal of Current Research in Biosciences and Plant Biology, 2014a; 1(5): 38-44.
45. Babiah PS, Upreti DK, John SA. An in vitro analysis of antifungal potential of lichen species *Parmotrema reticulatum* against phytopathogenic fungi. International Journal of Current Microbiology and Applied Sciences, 2014b; 3(12): 511-518.
46. Rashmi S, Rajkumar HG. Efficacy of lichen extracts as biocontrol agents against *Fusarium oxysporum* sp. *capsici*. Advances in Applied Science Research, 2014; 5(5): 273-277.
47. Javeria S, Shahi SK, Shahi MP, Yadava YK. Isolation of lichen-

forming fungus of *Everniastrum cirrhatum* and evaluate its Antagonistic and Antimicrobial Activity. American Journal of Ethnomedicine, 2014; 1(5): 361-367.
48. Hoda S, Vijayaraghavan P. Evaluation of antimicrobial prospective of *Parmotrema perlatum* hexane extract. International Journal of Pharmaceutical Research and Allied Sciences, 2015; 4(2): 47-53.
49. Valadbeigi T, Shaddel M. Antimicrobial and antifungal activities of Gelatinose and non-Gelatinose Lichen Species. J Arch Mil Med, 2015; 3(4): e31610.
50. Babiah PS, Upreti DK, John SA. Assessment of fungicidal potential of lichen *Heterodermia leucomelos* (L.) Poelt against pathogenic fungi. Current Research in Environmental and Applied Mycology, 2015; 5(2): 92–100.
51. Karabulut G, Ozturk S. Antifungal activity of *Evernia prunastri, Parmelia sulcata, Pseudevernia furfuracea* var. *furfuracea*. Pak J Bot, 2015; 47(4): 1575-1579.
52. Rashmi S, Rajkumar HG. Evaluation of fungistatic potential of lichen extracts against *Fusarium solani* (Mart.) Sacc. causing Rhizome rot disease in Ginger. Journal of Applied Pharmaceutical Science, 2015a; 5(10): 67-72.
53. Rashmi S, Rajkumar HG. Evaluation of antifungal activity of lichen extracts against phytopathogenic fungi *Macrophomina phaseolina* (Tassi) Goid. International Journal of Current Research, 2015b; 7(7): 17718-17721.
54. Houshyar F, Jamshidi S, Sohrabi M. Antimicrobial *in vitro* and *in vivo* potential of five lichen species on *Fusarium oxysporum* and *Ralstonia solanacearum*, agents of potato rots. Agroecology Journal, 2016; 11(4): 87-94.
55. Hameed HN, Ali S, Hassan B. Antifungal activity of a chemically induced mutant variant of *Xanthoria parietina*. Biologia (Pakistan), 2017; 63(1): 79-85.
56. Ankith GN, Rajesh MR, Karthik KN, Avinash HC, Prashith Kekuda TR, Vinayaka KS. Antibacterial and antifungal activity of three *Ramalina* species. Journal of Drug Delivery and Therapeutics, 2017; 7(5): 27 -32.
57. Kim YS, Lim CH. Isolation and structure elucidation of antifungal compounds from the antarctic lichens, *Stereocaulon alpinum* and *Sphaerophorus globosus*. Korean Journal of Agricultural Science, 2020; 47:183-191.
58. Yadav H, Nayaka S, Dwivedi M. Analytics on antimicrobial activity of Lichen extract. *J Pure Appl Microbiol,* 2021; 15(2):701-708.
59. Sahoo B, Dash S, Parida S, Sahu JK, Rath B. Antimicrobial activity of the lichens *Parmotrema andium* and *Dirinaria applanate*. Journal of Applied Biology and Biotechnology, 2021; 9(04): 93-97.
60. Tekiela A, Łukasz F, Andrusiewicz M, Bara G, Seaward MRD, Kapusta I, Czarnota P. Can lichen secondary compounds impact upon the pathogenic soil fungi *Fusarium oxysporum* and *F. avenaceum*? Folia Cryptogamica Estonica, 2021; 58: 165–181.
61. Paguirigan JA, Liu R, Im SM, Hur J, Kim W. Evaluation of Antimicrobial Properties of Lichen Substances against Plant Pathogens. Plant Pathol J. 2022; 38(1): 25-32.
62. Taghiyeva A, Dülger AFT, Yörük E, Engin TA. Investigation of the antifungal activity of lichen (*Usnea longissima*) extracts against *Fusarium graminearum.* Anatolian Journal of Botany, 2022; 6(2): 104-108.
63. Pradhan S, Dash S, Parida S, Sahoo B, Rath B. Antioxidant and antimicrobial activities and GC/MS-based phytochemical analysis of two traditional Lichen species *Trypethellium virens* and *Phaeographis dendritica*. Journal of Genetic Engineering and Biotechnology, 2023; 21:41.
64. Taylor JA, Fourie T, Powell M, Chianella I. Evidence for some antimicrobial properties of English churchyard lichens. Access Microbiology, 2023; 5:000536.