REVIEW ARTICLE

Bioactive Compounds of Bryophytes: Unveiling Antimicrobial Properties and Therapeutic Potential

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Abstract

Bryophytes, often considered less evolved than their vascular counterparts, have nonetheless developed an impressive array of chemical defenses that allow them to thrive on land. These ancient plants-close relatives of the earliest terrestrial species-possess remarkable pharmacological properties. Their phytochemistry includes a diverse range of bioactive compounds, such as lipids, proteins, steroids, organic acids, alcohols, terpenoids and polyphenols. Notably, substances derived from various bryophyte species are widely used in antitumor, antipyretic, insecticidal and antimicrobial applications. In this review, we explore the antifungal potential of three Bryophyta divisions: mosses (Musci), hornworts (Anthocerotae) and liverworts (Hepaticae). Compounds like riccardin C, riccardin D, marchantin E, Bis-Bibenzyl and marchantin A have shown promise in treating diverse diseases, including cancer, cardiovascular conditions, nervous disorders, H1N1 influenza and lung ailments.

Highlights

- The review provides a comprehensive overview of the bioactive compounds present in bryophytes.
- Elucidates the therapeutic potential of bryophytes in medicinal applications.
- The article presents detailed data on the antimicrobial activity of bryophyte extracts against various microorganisms.
- The article explores perspectives and potential developments in the field of bryophyte-based medicine.

Keywords: Antimicrobial, Bioactive, Bryophytes, Marchantin, Riccardin, Therapeutic.

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Introduction

Bryophytes represent the second largest category of land plants after angiosperms within the biosphere. Over 24000 species of mosses, hornworts and liverworts are collectively identified as bryophytes that are crucial parts of the ecosystem and biodiversity (Alves *et al*., 2022). Sathish *et al*. (2013) reported the 2486 bryophyte species and 482 genera from India. Southern Africa is occupied by more than 300 different species of liverwort. In Guizhou Province, a karst sandy desertification segment in China comprises more than 145 species from 56 genera of bryophytes. As bryophytes have a high-water retention capacity, they have been exploited to regulate stormwater and they serve as excellent moisture buffers in many habitats (Dziwak *et al*., 2022). Fig. 1 mentions the photographic images of bryophytes in their natural habitat,

Several bryophytes are commonly cast by tribal people of Africa, North America, Argentina, Australia, China, Europe, Japan, Nepal, New Zealand, Pakistan, Poland, Taiwan, Turkey and India for the treatment of diverse ailments. Hepatic illnesses, skin diseases, cardiovascular diseases, wound healing, etc. and several other diseases (Chandra *et al*., 2017). Some liverwort and moss extracts possess antibacterial, antifungal, antipyretic, antiviral and antitumor properties (Andrea *et al*., 2010). Although numerous tribes across the globe use bryophytes as common medicines, due to active constituents and phytopharmacology of bryophytes have been performed only in the last few decades (Dey and Mukherjee, 2015).

To date, only a negligible number of studies have investigated the medicinal value, metabolite profile and biological potential of bryophytes. Hence, the present review mainly addresses comprehensive information on the medicinal implications, bioactive molecule profile and biological properties of bryophytes.

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Traditional and medicinal potential of Bryophytes

Humans have examined plant sources for the treatment of ailments since the commencement of time. The medicinal and anti-infective properties of mosses were first identified by the Chinese and Native Americans thousands of years ago. Mosses have been used in many different contexts since antique times (Benek *et al*., 2022). Specifically, bryophytes have been used in America, China and India for their medical benefit (Glime, 2007). Traditionally, many bryophytes have been used to treat liver disease, ringworm disease, heart disease, fever, urinary and digestive problems, lung disease, and skin problems (Glime, 2017).

Fig.1: Natural habitat of bryophytes, A) *Barchymenium turgidum* Broth. ex Dixon, B) *Campylopus* sp., C) *Plagiochasma appendiculatum* L., D) *Cyathodium tuberosum*, E) *Anthoceros* sp., F) *Bryum coronatum* Schwaegr and G) *Octoblepharum albidum* (Ruturaj S. Shete)

Several rosette-forming *Riccia* species are externally used for treating ringworms (Saxena and Harinder, 2004). *Sphagnum* mosses were also widely used for surgical dressings during the First World War (Glime, 2007). The thin paste of thalli of *Plagiochasma appendiculatum* has been applied externally to cure skin problems (Shirsat, 2008). Liverworts such as *Targionia hypophylla* and *Frullania ericoides* have been commonly used to treat scabies, itching and other skin disorders caused by the Irula tribe (Remesh and Manju, 2009). Several species of bryophytes, including *Plagiochasma appendiculatum*, *Conocephalum conicum*, *Bryum argenteum* and *Mnium marginatum,* have been cultivated by traditional healers to cure burns, injuries, wounds and skin problems (Singh *et al*., 2011). In ancestral Indian medicine, *Conocephalum cinicum* and *Wiesnerella denudata* were used to treat gallstone diseases (Glime, 2017). Moreover, hepatitis diseases have been caused by using *Marchantia paleacea* var. *diptera* and *M. convoluta* (Sabovljevic *et al*., 2011; Chandra *et al*., 2017).

Chinese people prepare tea from *Polytrichum commune,* which aids in the dissolution of gall bladder and kidney stone particles (Chandra *et al*., 2017). Moreover, in ancestral Chinese medicine, *P. commune* was used to treat diseases such as fever, hemostatic disease, traumatic damage to pneumonia and lymphocytic leukemia (Ozturk *et al*., 2018). *Plagiochasma commune* is used to reduce fever and tenderness (Paliwal *et al*., 2020). *Funaria hygrometrica* was used for curing burns, wounds, blood pressure and cardiovascular diseases (Muhammad *et al*., 2018). Phytochemical compounds from diverse groups, such as sesquiterpenoids, monoterpenoids, diterpenoids, triterpenoids, flavonoids, bibenzyls and bisbibenzyls, are thought to be responsible for the anticancer properties of bryophytes (Dey and Mukherjee, 2015; Pherkop *et al*., 2021). The complete thallus of *Sphagnum fembriatm* has been used medicinally for the treatment of hypertension and cardiac matter (Bandyopadhyay *et al*., 2022). Volatile organic compounds from bryophytes, which have bioactive characteristics and can be exploited in biological prospecting and biotechnological customs, are found logically (Alves *et al*., 2022). The shocking increase in deaths caused by cancer has encouraged researchers to search for effective anticancer drugs to stop the spread of the disease as well as cure it (Zafar *et al*., 2023). Fig. 2 Represents the structures of notable bioactive metabolites of bryophytes, with Table 1 listing the chemical structures, systematic names, molecular formulas and medicinal uses of the bioactive compounds isolated from bryophytes. Moreover, Table 2 enlists the other phytochemicals detected from bryophytes.

Antimicrobial Activity of Bryophytes-a global Scenario

The pioneer worker who studied extracts of *Conocephalum conicum* (L.) Dumort. for antimicrobial activity, but the extracts did not show any antimicrobial activity against the verified pathogenic organisms (Hayes, 1947). According to (Madsen and Pates, 1952), antimicrobial substances can be found in floridia growing on chlorophyllose plants. Later, Pates and Madsen (1955) studied bryophytes *viz. Conocephalum conicum* (L.) Dumort, *Sphagnum strictum* Sull., *Dumortiera hirsuta* (Sw.) Nees and *S. portoricense* Hampe were found to be active against *Staphylococcus aureus* Rosenbach, *Candida albicans* Berkhout and *Pseudomonas aeruginosa,* respectively. Additionally, these extracts showed antibacterial activity against *E. coli* and several other microbial strains. Bryophytes such as *Dicranumscoparium* Hedw. (moss), *Porella platyphylla* (L.) Pfeiff. and *Marchantia polymorpha* L. were found to be considerably active against the bacteria *viz. Bacillus subtalis* Cohn, *Sarcina lutea* Good. and *S. aureus* Rosen. Notably, numerous secondary metabolites are found in bryophytes *viz.* Herbertane-type sesqui-terpenoids and diterpenoids exhibit antimicrobial activity against *Rhizoctonia solani* Kuhn and *Phythium debaryanumR*. *Hesse* and *Botrytis cinerea* Pers (Asakawa, 1981). Analyses of bryophytes such as *Conocephalum conicum*, *Mnium umdulatum* Hedw. and *Leptodictyum riparium* (Hedw.) Warnst against eight pathogenic bacteria because of their antibacterial potential was found to be effective (Castaldo *et al*., 1988).

The calculated antibacterial activity of the mosses, *viz. Sphagnum magellanicum* Brid.*, Hypnum amabile* (Mitt.) Hampe and liverworts *Trichocoleatomentos* and *Metzgeria decipiens* (C. Massal.) Schiffn. against the bacteria *Bacillus subtalis*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Staphylococcus aureus* from commercial fruit juices (Rodriguez *et al*., 1996). Studied the *Pleurochaetesquarrosa* (Brid.) Lindb. in acetone extracts against 11 human pathogenic bacteria (Basile *et al*., 1998). The extracted pigments of bryophytes exhibited antibiotic effects on gram-positive bacteria, *viz. Aureobacterium liquefaciens*, *Arthrobacter globiformis*, *Bacillus brevis*, *B.cirulans*, *B. subtilis* and *Curlobacteriumplantanum* were obtained (Wakulinski *et al*., 2003).

Table 1: List of bryophytes and biomolecules identified with their biological and medicinal implications

S. No.	*Name of Bryophyte*	*Biomolecule detected*	*Molecular formula*	*Medicinal uses*	*Reference*
1	*Asterella angusta* (Stephani) Pande, K. P. Srivast. & Sultan Khan	Riccardin C	$C_{28}H_{24}O_4$	Anticancer.	Xu *et al*. 2010
2	*Asterella angusta* (Stephani) Pande, K. P. Srivast. & Sultan Khan	Dihydroptychanto A	$C_{28}H_{24}O_4$	Pro-apoptotic activity.	Nandy *et al*. 2020
3	*Philonotis* sp.	Triterpenoidal saponins	$C_{65}H_{102}O_{29}$	Heal burns for adeno-pharyngitis, antipyretic.	
4	*Rhodobryum giganteum* (Schwaegr.) Par.	7-8-Dihydroxycoumarn	$C_9H_6O_4$	Cardiovascular problems and nervous prostration, anti-hypoxia, antipyretic, diuretic and antihypertensive.	Mishra *et al*. 2014
5	*Bryum* sp.	Triterpenoidalsapns	$C_{65}H_{102}O_{29}$	Healing wounds, burns and fungal infections.	
6	*Conocephalum conicum* (L.) Dum.	Lunularin	$C_{14}H_{14}O_2$	Anticancer and cytotoxicity.	Kakoli *et al*. 2022
7	*Cratoneuron filicinum* Spruce	Terpenoids and acetogenins	$(C_5H_8)_n$ and $C_{37}H_{66}O_6$	Heart disease.	Pant *et al*. 1989
8	*Dicranium* sp.	Triglycerides	$C_6H_8O_6$	Diabetes/ prediabetes.	Alam, 2021
9	*Ditrichum pallidum* (Hedw.) Hampe	Phenols	C_6H_6O	Treats convulsions.	Kakoli *et al*. 2022
10	*Dumortiera hirsuta* (Sw.) Nees	Riccardin D	$C_{28}H_{24}O_4$	Antibiotics and anticancer.	Azuelo *et al*. 2011
11	*Fissidens nobilis* Griffith	Terpenoids	$(C_5H_8)_n$	Hair fall.	
12	*Frullania muscicola* Stephani	Marchantin E	$C_{29}H_{26}O_6$	H1N1 anti-influenza.	Iwai *et al*. 2011
13	*Frullania tamarisci* (L.) Dumort and *Frullania dilatata* (L.) Dumort.	Sesquiterpene lactone	$C_{22}H_{30}O_7$	Cardiovascular diseases.	Asakawa *et al*. 2017
14	*Jungermannia fauriana* Beauverd	Jungermannenone A	$C_{20}H_{28}O_2$	Anticancer.	Kakoli *et al*. 2022
15	*Marchantia convolunta* C. Gao & G.C. Zhang	β-Caryophyllens	$C_{15}H_{24}$	Cytotoxic against liver & lungs carcinoma (Anticancer).	Xiao *et al*. 2006
16	*Marchantia polymorpha L.*	Bisbibenzyl	$C_{20}H_{22}O_4S_2$	Medicaments for resisting inflammation and rheumatic arthritis or treating tumours caused by inflammation.	Nandy *et al*. 2020
17	*Marchantia polymorpha* L.	Marchantin A	$C_{28}H_{24}O_5$	Used as diuretics for liver ailments, insect bites boil and abscesses, treat pulmonary tuberculosis and used to cure cuts.	Mishra *et al*. 2014

18	*Marchantia polymorpha* L.	Marchantin A	$C_{28}H_{24}O_5$	Anticancer.	Nandy *et al*. 2020
19	*Marchantia polymorpha* L.	Marchantin A & Marchantin B	$C_{28}H_{24}O_5$ & $C_{29}H_{26}O_6$	Anticancer, antipyretic and antibacterial, decrease the cell viability of T47D & A256 cell lines.	Kakoli *et al*. 2022
20	*Marchantia polymorpha* L.	Marchantin A	$C_{28}H_{24}O_5$	Used for treatment of snake bite.	Bishnu *et al*. 2021
21	*Marchantia polymorpha* L.	Marchantin E	$C_{29}H_{26}O_6$	Burns, for cardiovascular disease. To treat boils and abscesses as a source of antibiotics.	
22	*Plagiomnium* sp. *Mnium* sp.	Triterpenoidal saponins	$C_{65}H_{102}O_{29}$	Against infections and swellings. Poultice as padding under splints to set broken bones.	Mishra *et al*. 2014
23	*M. palmate Dumortiera hirsute* (Sw.) Nees *Pallavicinia* sp.	Plagiochiline A	$C_{19}H_{26}O_6$	Exhibits antileukemic/anti-microbial activity.	
24	*Marchantia paleacea* var. diptera	Superoxide dismutase	$C_{22}H_{34}MnN_{10}O_{11}$	Cancer, inflammatory diseases, cystic fibrosis, ischemia, ageing, rheumatoid arthritis, neurodegenerative diseases and diabetes.	Alam, 2021
25	Marchantia papillate	Riccardin C	$C_{28}H_{24}O_4$	Anti-inflammatory, treat inflammation caused by fire antibacterial, treat boils.	Negi *et al*. 2018
26	*Mnium cuspidatum* Hedw.	Saponarin	$C_{27}H_{30}O_{15}$	Used to cure nose bleeding.	Pant *et al*. 1989
24	*Plagiochila beddomei* Steph.	Phenolics	C_6H_5OH	Inflammation and associated disorders.	Gahtori *et al*. 2019
28	*Plagiochasma appendiculantum* Lehm. & Lindenb.	Saponins & Carbohydrates	$C_{58}H_{94}O_{27}$ & $C_6H_{12}O_6$	It cures skin diseases.	Kakoli *et al*. 2022
29	*Polytrichum pallidiserum* Funck	1-O-Methyldihydroohioens B	$C_{25}H_{22}O_5$	Inhibit human glioblastoma multiforme U-251 MG and 1,14-di-O-methyldihydroohioens B inhibit human lung carcinoma A549 & human melanoma RPMI-7951 cell lines.	Chandra *et al*. 2019
30	*Pellia endiviifolia* (Dicks.) Dumort.	Sacculatal	$C_{20}H_{30}O_2$	Human melanoma.	Dziwak *et al*. 2022
31	*Polytrichastrum alpinum* (Hedw.) G.L. Sm.	Ohioensin F	$C_{23}H_{16}O_6$	Atherosclerosis and acts as a strong antioxidant.	Chandra *et al*. 2019
32	*Polytrichum commune* Hedw.	Ohioensin H	$C_{23}H_{16}O_5$	Human T cell leukemia (6 T-CEM), human breast adenocarcinoma (MDA-MB-435).	

33	*Polytrichum ohioense* Renauld & Cardot.	Ohioensin B	$C_{24}H_{18}O_5$	Nearly all Ohioensins show cytotoxic activities against various cell lines, thus these can be used for the treatment of different cancers.	
34	*Polytrichum ohioense* Renauld & Cardot	Ohioensin A	$C_{23}H_{16}O_5$	Ohioensin A exhibits cytotoxicity against murine leukemia (PS) and breast cancer cell lines.	
35	*Polytrichum ohioense* Renauld & Cardot	Ohioensin C	$C_{23}H_{16}O_5$		
36	*Polytrichum ohioense* Renauld & Cardot.	Ohioensin D	$C_{24}H_{18}O_6$	Ohioensin C, Ohioensin D and Ohioensin E show activity against 9PS, murine P388 leukemia.	
37	*Polytrichum ohioense* Renauld & Cardot.	Ohioensin E	$C_{25}H_{20}O_6$		
38	*Polytrichum pallidisetum* (Funck) G. L. Smith	Pallidisetin A	$C_{23}H_{18}O_3$	Anti-inflammatory.	Kakoli *et al.* 2022
39	*Polytrichum pallidisetum* (Funck) G. L. Smith	Pallidisetin B	$C_{23}H_{18}O_3$	It is cytotoxic against U-251MG and RPM 1-7951 human tumor cell lines.	
40	*Plagiochila* sp.	Plagiochilal B	$C_{15}H_{20}O_3$	Exhibits anti-leukemic activity/ antimicrobial activity.	
41	*Plagiomnium* sp.	Triterpenoidalsaponins	$C_{65}H_{102}O_{29}$	For infections and swellings	Azuelo *et al.* 2011
42	*Philonotis* sp.	Triterpenoidalsaponins	$C_{65}H_{102}O_{29}$	Heal burns for adenopharyngitis, antipyretic & antidotal.	
43	*Reboulia hemisphaerica* (L.) Raddi	Riccardin C	$C_{28}H_{24}O_4$	Chemoresistant prostate cancer PC3 cells.	Dziwak *et al.* 2022
44	*Reboulia hemisphaerica* (L.) Radii	Benzoquinone	$C_6H_4O_2$	Hemostasis treats wounds.	Asakawa *et al.* 2012
45	*Rhodobryum roseum* (Hedw.) Limpr.	Flavonoids	$C_{27}H_{30}O_{15}$	Nervous disorders and cardiovascular diseases.	Pant *et al.* 1989
46	*Sphagnum palustre* L.	Fulvic acid	$C_{14}H_{12}O_8$	Anticancer.	Kakoli *et al.* 2022
47	*Thuidium tamariscellum* (C. Muell.) Bosch. & Sande-Lac., Bryol. Jav.	Terpenoids	$(C_5H_8)_n$	Terpenoids are used for the treatment of diabetes and cardiovascular diseases.	Gahtori *et al.* 2019
48	*Taxiphyllum taxirameum* (Mitt.) M. Fleisch.	Phenols	C_6H_5OH	Hemostasis, treatment of external wounds.	Chandra *et al.* 2017
49	*Thudium tamariscinum* W. P. Schimper	Phenolics	C_6H_5OH	Skin diseases and inflammatory bowel disease.	Alam, 2021
50	*Wiesnerella denudata* (Mitt.) Steph.	Costunolide	$C_{15}H_{20}O_2$	The anti-allergic effect, bone remodelling effect, prevention of neurodegenerative ailment, prevention of lung disease and anti-diabetic effect.	

Table 2: Other phytochemicals detected from bryophytes

S. No.	*Bryophytes*	*Biomolecule detected*	*Molecular formula*	*Reference*
1	*Asterella* sp. P. Beauv.	Skatole	C_9H_9N	Dziwak *et al*. 2022
2	*Asterella angusta* (Stephani) Pande, K.P. Srivast. & Sultan Khan	Riccardin C	$C_{28}H_{24}O_4$	Xie *et al*. 2010
3	*Bazzania trilobata* (L.) Gray	Isoplagiochin D	$C_{28}H_{24}O_4$	Scher *et al*. 2004
4	*Conocephalum conicum* (L.) Dum	Methyl cinnamate	C H O	Ghani *et al*. 2016
5	*Cyathodium foetidissimum* Schiffn.	Skatole	C_9H_9N	Dziwak *et al*. 2022
6	*Frullania nepalensis* (Spreng.) Lehm. & Lindenb., *Frullania asagrayana* Montagne	Tamariscol	$C_{15}H_{26}$	Tori *et al*. 1990
7	*Frullania inouei* S. Hatt.	Chrysotobibenzyl	$C_{19}H_{24}O_5$	Nandy *et al*. 2020
8	*Gymnomitrion obtusum* (Lindb.) Pears.	Gymnomitrol	$C_{15}H_{24}O$	Dziwak *et al*. 2022
9	*Hypnum plumaeforme* Wilson	Sacculatal	$C_{20}H_{30}O_2$	Bandyopadhyay *et al*. 2022
10	*Isothecium subdiversiforme* Broth and *Thamnobryum sandei* Besch.	Trewiasine	$C_{37}H_{52}ClN_3O_{11}$	Dziwak *et al*. 2022
11	*Jungermannia* sp. L.	Jungermannenone A	$C_{20}H_{28}O_2$	
12	*Leptolejeunea elliptica* Lehm. & Lindenb.	p-ethyl phenyl acetate	$C_{16}H_{16}O_2$	Sakurai *et al*. 2020
13	*Lophocolea heterophylla* (Schrad.) Dumort., and *Lophocolea bidentata* (L.) Dumort.	Geosmin	$C_{12}H_{22}O$	Dziwak *et al*. 2022
14	*Mannia fragrans* (Balbis) Frye et L. Clark	Grimaldone	$C_{15}H_{24}O$	
15	*Marchantia polymorpha* L.	Plagiochin E	$C_{28}H_{24}O_4$	Wu *et al*. 2010
16	*Marchantia paleacea* var. diptera and *Marchantia Polymorpha* L.	Isoplagiochin B	$C_{28}H_{22}O_4$	Bandyopadhyay *et al*. 2022
17	*Marchantia* species L.	Marchantin A	$C_{28}H_{24}O_5$	Asakawa, 1994
18	*Marsupella emarginata* (Ehrh.) Dumort.	Marsupellone	$C_{15}H_{22}O$	
19	*Plagiochila sciophila* Nees	Bicyclohumulenone	$C_{15}H_{24}O$	Asakawa, 2007
20	*Plagiochila stephensoniana*	3-Methoxy-4-hydroxybibenzyl	$C_{15}H_{16}O_2$	Asakawa *et al*. 2017
21	*Porella vernicosa* Lindb.	Polygodial	$C_{15}H_{22}O_2$	Asakawa, 2007
22	*Plagiochasma intermedium* Lindenb. & Gotische	Riccardin C	$C_{28}H_{24}O_4$	Xie *et al*. 2010
23	*Polytrichum commune* Hedw.	Ohioensin H	$C_{23}H_{16}O_5$	Fu *et al*. 2009
24	*Polytrichum ohioense* Renauld & Cardot.	Ohioensin D	$C_{24}H_{18}O_6$	
25	*Polytrichum pallidiserum* Funck	1-O-Methyldihydroohioensin B	$C_{25}H_{22}O_5$	
26	*Polytrichum pallidiserum* Funck	1-O-Methylohioensin B	$C_{25}H_{20}O_5$	
27	*Riccardia crassa* Schwagr.	Riccardiphenol C	$C_{21}H_{28}O_2$	Perry *et al*. 1995
28	*Riccardia multifida* (L.) Gray	Isoplagiochin A	$C_{28}H_{22}O_4$	Bandyopadhyay *et al*. 2022
29	*Symphyogyna brongniartii* Mont.	Geosmin	$C_{12}H_{22}O$	Dziwak *et al*. 2022
30	*Takakia lepidozioides* S. Hatt. & Inoue	Coumarin	$C_9H_6O_2$	Asakawa *et al*. 2015

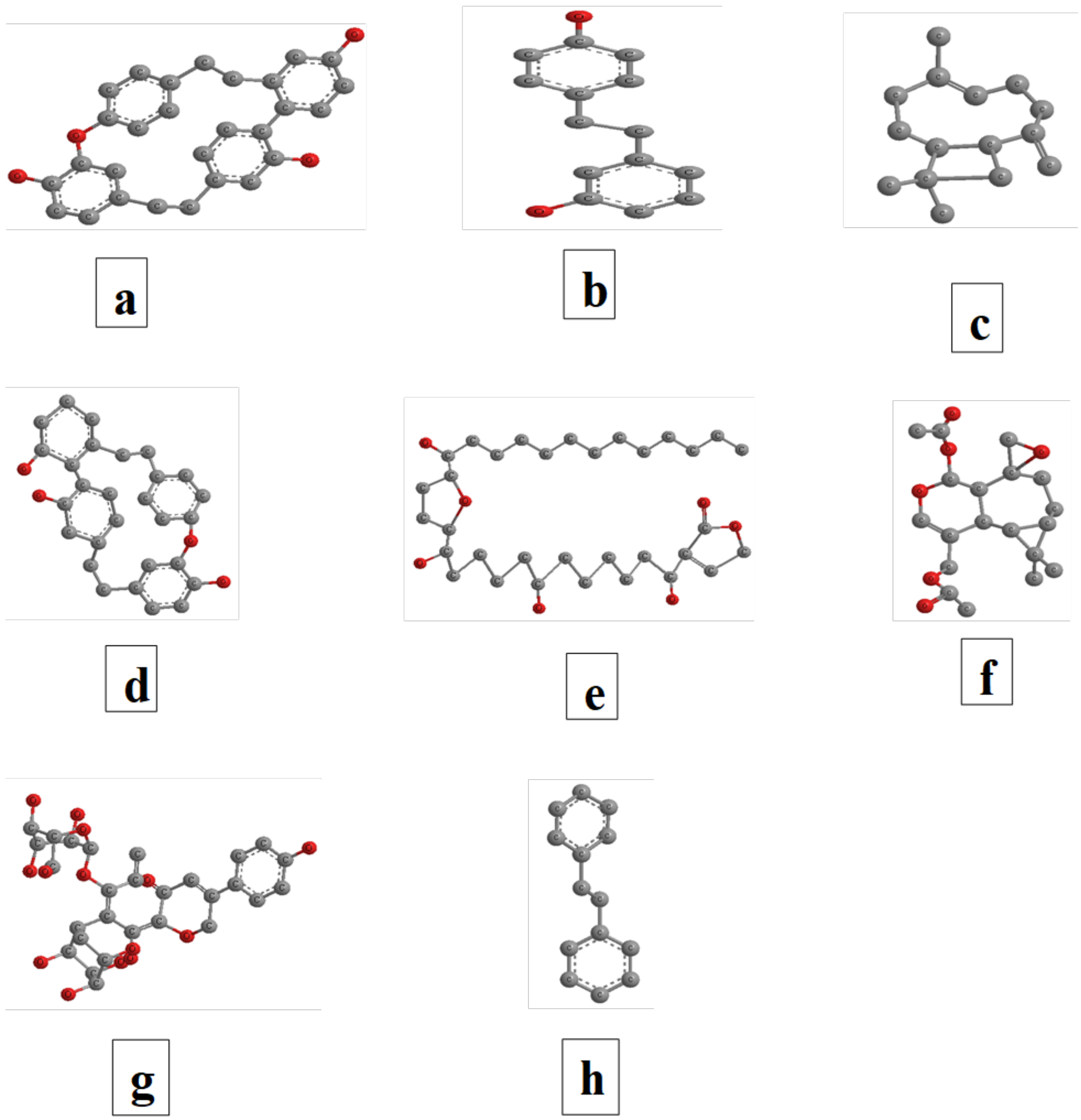

Fig. 2: Structures of notable bioactive metabolites of bryophytes: a. Riccardin C ($C_{28}H_{24}O_4$) b. Lunularin ($C_{14}H_{14}O_2$) c. β-Caryophyllens ($C_{15}H_{24}$) d. Riccardin D ($C_{28}H_{24}O_4$) e. Acetogenin ($C_{37}H_{66}O_6$) f. Plagiochiline A ($C_{19}H_{26}O_6$) g. Saponarin ($C_{27}H_{30}O_{15}$) h. Bibenzyl ($(C_6H_5CH_2)_2$). The structures are drawn from ChemDraw software (Ruturaj S. Shete)

The antibacterial activity of these strains against gram-positive and gram-negative bacteria from liverworts and mosses (Zhu *et al*., 2006). Clarify a major component of Riccardin C of *Plagiochasma intermedium* Lindenb. and Gottsche, which exhibited antifungal activity against *Fusarium oxysporum* and *Botrytis cinerea* at aMIC of 32 µg/ml, but the other three chlorinated bis(bibenzyls), *viz*. bazzanin S, isoplagiochin D and bazzanin B from Bazzania trilobata (L.) A. Gray and isoplagiochin D, which were found to be most active against fungi such as *Phythophthora infestans*, *Cladosporium cucumerinum*, *Septoria tritici* and *Pyricularia oryzae* (Qu *et al*., 2007).

Plagiochin E (PLE) was extracted from the liverwort *Marchantia polymorpha* L. Its impact on cell wall chitin synthesis in *Candida albicans* was subsequently determined. The cell wall was completely damaged due to the antifungal activity of Plagiochin E (Wu *et al*., 2008). The compounds obtained from bryophytes have been shown to reverse the conventional antibiotic resistance that develops in human pathogenic fungi (Xie and Lou, 2008). As detected in *Scapania verrucosa*, liverwort contains an endophytic fungus called *Chaetomium fusiforme*. Gas chromatography-mass spectrometry was used to analyze the ether content of the *S. verrucosa* and *Chaetomium fusiforme* cultures. Additionally, compared with the host plant, *Chaetomium fusiforme* has been shown to have a greater range of antitumor and antimicrobial activity (Guo *et al*., 2008). The antibacterial and antifungal properties of methanol extracts from mosses *viz. Pleurozium schreberi* (Willd. Ex Brid.) Mitt., *Palustriella commutata* (Hedw.) Ochyra, *Homalothecium* *philippeanum* (spruce) Schimp., *Anomodon attenuatus* (Hedw.) Huebener, *Rhytidium rugosum* (Hedw.) Kindb., *Hylocomium splendens* (Hedw.) Schimp., *Dicranum scoparium* Hedw. and *Leuca glaucum* (Hedw.) Angstrwas evaluated for its ability to treat six bacterial species and seven fungal species through disc diffusion and microdilution (Veljic *et al*., 2008).

Test of the antibacterial activity of *Fontinalis antipyretica* Hedw, *Hypnum cupressiforma* Hedw, *Ptilidium pulcherrimum* (Weber) Vain and *Ctenidium molluskcum* (Hedw.) Mitt. and the antifungal activity of methanolic extracts of *Ptilidium pulcherrimum* against gram-negative and gram-positive bacteria, and substantial results were reported associated with synthetic antibiotics and fungicides (Veljic *et al.,* 2009).

The antibacterial activity of *Sphagnum* acid and other phenolic compounds found in *Sphagnum papillosum* Lindb. to identify the phenolic compound and test for antibacterial properties at a pH suitable for the undissociated forms in the leaves of *Sphagnum papillosum* Lindb. (Mellegard *et al*., 2009). Five bryophyte species, *Platyhypridium riparioides* (Hedw.) (Dixon, *Anomodon viticulosis* (Hedw.) *Polytrichostrum formosum* (Hedw.) G. L. Sm., *Plasteurhynchium meridionale* (Schimp.) M. Fleish and *Ctenidium molluscum* (Hedw.) Mitt. The ethanol extract was tested on bacteria *viz. Bacillus cereus*, *Bacillus subtilis*, *Micrococcus leuteus*, *Staphylococcus aureus*, *E. coli*, *Enterobacter aeruginosa*, *Proteus vulgaris*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Pseudomonas putida*, *Salmonella typhimurium*, *Salmonella typhi* and *Neisseria gonorrheae*, *Candida albicans*, *Rhodotorula rubra*, *Kluyveromyces fragilis*, *Kluyveromyces marxianus* and *Debaryomyces hansenii* according to disc diffusion performance. Plant extracts of *P. meridionale* and *A. viticulosis* were found to be effective against all the tested microorganisms (Dulger *et al*., 2009).

The antimicrobial activity of *Ptilidium pulcherrimum* (Weber) Vain was assessed. antibacterial activity was assessed in vitro using a methanol extract against six fungal and five bacterial species. Microdilution and disc diffusion techniques were used for testing in vitro antibacterial activity. The extract had a stronger effect on the tested gram-positive bacteria than on the other gram-negative bacteria. A microdilution technique was used to assess the antifungal properties of the methanol extracts (Veljic *et al*., 2010).

In an in vitro study of six acrocarpous moss species, their antimicrobial activities were evaluated against eight microorganisms using extracts prepared with methyl alcohol, ethyl alcohol, acetone, and chloroform. Methyl alcohol extracts exhibited the highest antimicrobial efficacy, whereas chloroform extracts showed the lowest. The results were compared to standard antibiotics: ampicillin (10µg), erythromycin (15µg), vancomycin (30µg) and ketoconazole (50µg) (Elibol *et al*., 2011).

Savaroglu *et al*., (2011) reported the anticancer and antimicrobial effects of *Fontinalis antipyretica* Hedw. in methanol, chloroform, acetone and ethyl acetate extracts. Antimicrobial activity was assessed using a good diffusion method against eight bacterial and seven fungal strains. Extracts of acetone, chloroform and ethyl acetate showed activity against almost all the tested strains. These authors suggested that *F. antipyretic* may be an anticancer and antimicrobial agent. The antifungal and antibacterial activities of mosses such as *Funaria hygrometrica* Hedw., *Polytrichum juniperinum* Hedw., *Tortella tortuosa* (Hedw.) Limpr., *Hypnum cupressiforme* Hedw. and *Hypnum imponens* Hedw. against three fungal and six bacterial strains. Agar diffusion analysis and microdilution methods were used to test the activity of the strains. Extract of *Tortella tortuosa* (Hedw.) showed the highest antibacterial activity against *Pseudomonas aeruginosa* (5.9 MIC µg/ml). Mosses such as *Tortella tortuosa* (Hedw.) and *P. juniperinum* Hedw. reported the greatest inhibitory activity against the tested bacterial and fungal strains (Savaroglu *et al*., 2011).

It has been reported that *H. sericeum* (Hedw.) Schimp. (Brachytheciaceae) species strongly antibacterial activity against *P. aeruginosa* and has anticancer effects on C6 glioma cells (Pinar *et al*., 2011). Investigated the antimicrobial activity of several moss species from the Kastamonu region (*Bryum capillare* var. *capillare*, *H. sericeum* W. P. Schimper, *Plagiomnium affine* (Blandow ex Funck) T. J. Kop., *H. lutescens* H. Robinson, *Homalia besseri* Lobarzewski and *A. tenax* (Hedw.) C.E.O. Jensen) and reported that moss extracts have noticeable effects on *Salmonella enterica*, *C. albicans*, *S. flexneri*, *Bacillus megaterium* and *E. coli* (Altuner *et al*., 2011).

In Latvia, the antimicrobial activity of eleven bryophyte species was evaluated using ethanolic and aqueous extracts of *Bacillus cereus*, *E. coli* and *Staphylococcus aureus*. Both extracts showed remarkable activity against the tested bacteria (Nikolejeva *et al*., 2012). Intent antibacterial activity of *Octoblepharum albidum* Hedw. Against six bacterial strains by the microdilution method. The extracts were prepared in ethanol only or in combination with aminoglycosides. The results showed similar inhibitory effects against *E. coli* and *Klebsiella pneumonia* (MIC of 512µg/mL) (Vidal *et al*., 2012). The antimicrobial activity of *Rhodobryum ontariense* (Kindb.) Par. in Kindb. against eight bacterial strains. Dimethyl sulfoxide extracts from mosses were tested by the microdilution method, and the extracts were found to have remarkable activity against the tested bacteria (Pejin *et al*., 2012).

Initiate the antibacterial and antifungal activities of mosses *viz. Abietinell aabietina* (Hedw.) M. Fleisch., *Cratoneuron filicinum* (Fiorini-Mazzanti) Latzel, *Platyhypnidium riparoides* (Hedw.) Dixon, *Neckera crispa* Hedwig and *Campylium protensum* (Brid.) Kindb. against *Penicillium ochrochloron*, *P. funiculosum*, *Trichoderma viride*, *Aspergillus flavus*, *A. fumigatus* and *A. niger*. The methanolic extracts of all the studied mosses showed antimicrobial effects against all the tested microorganisms (Bukvicki *et al*., 2012). To investigate the antimicrobial activity of the pteridophyte *Azolla filiculoides* Lam. and the bryophyte species *Brachythecium buchananii* (Hook.) Jaeg has been tested for its potential antibacterial and antifungal activities using pharmacological, toxicological and microbiological tests (Angalao *et al*., 2012).

The antimicrobial efficiency of the seven mosses was assessed, and three liverwort extracts were prepared in ethanol, acetone and water. Bacterial strains such as *Candida albicans* and *Staphylococcus aureus* and fungal strains such as *Mucor rouxii* and *Penicillium notatum* were used to evaluate antimicrobial activity. The extract was obtained from *Riccia flacida* Lindenb. & Gottsche inhibited the growth of *S. aureus* and *C. albicans*. *Cyatodium aficanum* Mitt. showed activity against *Mucor rouxii*. The above results indicated that effective antimicrobial compounds can be sourced from *R. flacida* and *C. africanum*. In this particular work, *Artrichum undulatum* (Hedw.) P. Beauv. Antibacterial activity was tested using several moss species extracts, with ampicillin serving as a positive control, and the antibacterial activity against certain bacterial strains was tested using the agar diffusion technique (Olofin *et al*., 2013).

The *Artrichum undulatum* (Hedw.) P. Beauv. antibacterial activity for the first time, revealing that it is a naturally occurring antibacterial agent that may be useful as a medicine with sufficient scientific verification (Vats and Alam, 2013). Screening of antimicrobial activity of *Calliergonella cuspidate* Loeske, *Dicranum polysetum* Swartz. Musc. and *Hypnum cupressiforme* Hedw. against certain microorganisms and has shown significant results (Altuner *et al*., 2014).

Antimicrobial properties of *Mnium stellare* Hedw. was first described by Canli *et al*. (2015), who reported that *Mnium stellare* Hedw. has antimicrobial properties against *B. subtilis*, *S. aureus*, *S. carnosus*, *S. epidermidis* and *S. typhimirium*. The antimicrobial potentials of acetone and ethanol *Philonotis hastata* Wijk & Margadant. The results of the phytochemical screening confirmed the presence of alkaloids, flavonoids, cardiac glycosides and saponins. Plant extracts have been shown to have antibacterial effects on *Candida albicans*, *Aspergillus flavus* and *Staphylococcus aureus* (Makinde *et al*., 2015).

The antimicrobial activity of Nigerian mosses such as *Racopilum africanum* Mitten, *Cyclodictyon* species and *Calymperes erosum* C. Muller against pathogenic microorganisms was also analyzed. Organic solvents *viz*. Acetone, methanol and ethanol were used for the preparation of the extracts. The antimicrobial properties of these extracts were evaluated using the agar diffusion method. The extracts showed antimicrobial activity against the tested microorganisms. Methanolic and acetonic extracts showed less activity than the ethanolic extracts (Oyesiku and Caleb, 2015).

The antioxidant and antimicrobial properties of eight moss species from Turkey were assessed. The extracts were tested for antimicrobial activity against three fungal strains, six gram-negative bacterial strains, and four gram-positive bacterial strains. All moss extracts exhibited positive activity against all the organisms except the moss species *Homalothecium* nitens Limpr. Wijk & Margad. Among the mosses, *H. striatulum* and *H. sericeum* W. P. Schimper showed the highest antioxidant activity (Erturk *et al*., 2015).

The persistent antibacterial activity of 23 Bryophytes against larvae causes foulbrood disease in honeybee larvae (Sevim *et al*., 2017). According to Ma *et al*. (2017), prior research has shown that mosses can be extensively utilized in biomonitoring air pollution by enhancing particular compounds and elements via the moss-tag strategy. This survey helps us understand the variables affecting microbial populations in mosses and refine biomonitoring technology. The many bacteria associated with mosses may also be significant factors in connected biological processes. The antifungal activities of mosses such as *Hyophila javanica* Bridel, *Meteorium subpolytrichum* Brotherus, *Leucobryum aduncum*, *Dicranoloma reflexum* Renauld, *Dicranella coarctata* Bosch & Sande Lacoste and Isotheciopsis were inspected (Griff.) Nog. and *Homaliodendron flabellatum* (Sm.) M. Fleisch. against *Candida albicans*. Extracts of all the mosses at different concentrations inhibited the growth of *Candida albicans* except for the methanol extract of *Dicranoloma reflexum* Renauld and *Homaliodendron flabellatum* (Sm.) M. Fleisch. by (Junairiah *et al*., 2017).

The detected maximum level of antibacterial activity in *Plagiomnium undulatum* (Hedw.) T. J. Kop. and *Dryptodon pulvinatus* (Hedw.) Brid. compared to the earlier reported extracts of *Dicranum scoparium* Hedw. showed less antibacterial activity. However, two extracts from *Polytrichum juniperinum* Hedw. and *P. piliferum* Hedw. had little effect on gram-positive bacteria and lacked gram-negative bacteria. Antibacterial activity was not observed for the four ethanolic extracts of mosses, such as *Oxyrrhynchium hians* (Hedw.) Loeske, *Brachythecium albicans* (Hedw.) Schimp., *Syntrichia ruralis* (Hedw.) F. Weber & D. Mohr and *Ceratodon purpureus* (Hedw.) Brid. (Tomasz *et al*., 2017).

The 1940s saw the first accounts of the antibacterial properties of bryophytes. The exceptional antibacterial properties of only a handful of species (*Anomodon rostratus, Orthotrichum rupestre* and *Plagiomnium cuspidatum*) were discovered in the 1950s (Vollar *et al*., 2018).

Extract of *Funaria hygrometrica* Hedw. some bacterial strains from a human throat. The results showed that the *Funaria hygrometrica* Hedw. extracts were the antibiotics found on the test organisms *viz. Corynebacterium* sp., *Lactobacillus* species and *Staphylococcus* species (Akani *et al*., 2018). Extract of *Dryptodon pulvinatus* (Hedw.) Brid. and *Ceratondon purpureus* (Hedw.) Brid. and has good potential for antimicrobial and antioxidant activities (Wolski *et al*., 2021). Contaminations of virus-related and bacteriological diseases, such as those caused by an antitoxin for snake bites and pathological skin hits, are only a few of the many ailments for which Echinacea has a long history of customizing as a medicine. Conventionally, *Echinacea* was used to treat nasopharyngeal catarrh syndrome, tonsillitis, influenza-like contaminations, frequent impurities of the respiratory tract and minor urinary tract infections. *Magnolia officinalis* bark was used in ancient times in Japan and China for herbal medicine, often because of its delicacies for anxiety, sleep-related troubles and antipathy situations (Dimmito *et al*., 2021).

Study of secondary metabolites and antimicrobial properties of African tropical four mosses *viz. Archidium ohioense* Schimp. ex C. Mull., *Bryum coronatum* Schwagr. (acrocarps), *Rhacopilum africanum* Mitt. and *Thuidium gratum* (P. Beauv.) A. Jaeger screening for antimicrobial properties and secondary metabolites was performed on microorganisms and the extract of chloroform was shown to have an impact on *Escherichia coli* and *Staphylococcus aureus* (Isa *et al*., 2021).

Indian Antimicrobial Activity of Bryophytes

Mosses were ignored for their biochemical studies for a long time in India. Several chemicals present in mosses exhibit significant biological activity. Petroleum ether extracts of *Timiella* and *Barbula* were verified by (Gupta and Singh, 1971) for their antibacterial activities against thirty-three bacterial strains of gram-positive and gram-negative bacteria, and significant positive results were found. Tests of bryophytes corresponding to *Pogonatum aloides* (Hedw.), *Diplophyllum albicans* (L.) and *Plagiothecium denticulum* (Hedw.) Schimp for its antimicrobial activity and found remarkable activity (Dikshit *et al*., 1982). The antimicrobial activity of the members of Marchantiales was not clear. Thirteen out of the 16 species tested were inhibitory. The family Rebouliaceae, which includes all 5 species of the analyzed samples, has chiefly marked antibiotic activity (Banerjee *et al*., 1979). Carried out inspection of the antimicrobial activities of some bryophytes, which showed that nearly 200 bryophytic plants had been surveyed thus far to classify such activity of which 63-76% of the Bryophytes showed positive results (Banerjee, 2000).

In India, earlier bryologists were widely focused on the systematics of bryophytes; therefore, no significant work in the past has known antimicrobial activity. Currently, few researchers have investigated the antimicrobial activities of mosses, such as Subhisha and Subramoniam (2005), Bodade *et al*. (2008) and Deora and Guhil (2014; 2018). Mosses are the most studied mosses, followed by thalloid and leafy liverworts.

In vitro antifungal activity of *Pallavicinia lyellii* (Hook.) Gray against four fungi *viz. Aspergillus niger*, *A. fumigatus*, *Candida albicans* and *Fusarium oxysporum* were isolated by using direct dilution and disc diffusion methods. Hexane, water, and alcohol were used for preparing the extracts. The extract of the tested fungi exhibited remarkable activity, with the highest antimicrobial activity observed in the alcoholic extract (Subhisha and Subranomiam, 2006). The antimicrobial activity of *Palustriella commutate* (Hedw.) Ochyra extracts were to be effective against test organisms (Semra *et al*., 2006).

The antimicrobial properties of fifteen Indian mosses were assessed against five-gram-positive and six-gram-negative bacterial strains. Furthermore, *Barbula arcuate* Griff., *Barbula javanica* Dozy & Molk. and *Mnium marginatum* (Dicks.) P. Beauv. var. marginatum, *Brachythecium rutabulum* (Hedw.) Schimp., *Brachythecium populeum* (Hedw.) Schimp., *Entodon rubicundus* (Mitt.) A. Jaeger and *Sphagnum junghuhnianum* Dozy & Molk. found potential against the above-tested microorganisms (Singh *et al*., 2007). Screening of the antimicrobial activity of *Marchantia polymorpha* L. against bacterial strains *viz. Proteus mirabilis*, *Staphylococcus aureus* and *E. coli* and fungal strains such as *Aspergillus flavus*, *Aspergillus niger*, *Trychophyton mentagrophyes* and *Candida albicans* were used. The crude extract was prepared in methanol. All the fungal and bacterial strains were to be sensitive to the tested extracts. The results show that *Marchantia polymorpha* L. can be used as an antimicrobial drug in the future (Mewari *et al*., 2008).

The antifungal activities of two liverworts and twenty-one mosses were also studied. Extracts were prepared in ethanol, methanol, petroleum ether, acetone and water. All the extracts were mixed with Czapek-Dox medium at a ratio of 1:10. Fungal strains, namely, *Alternaria alternate*, *Fusarium oxysporum*, *F. solani*, *Macrophomina phaseolina*, *Pythium* species and *Verticillium dahliae,* were grown on these prepared extracts. The ethanolic extracts of mosses *viz. Bryum pallens* Sw., *Plagiomnium rugicum* (Laurer) T.J. Kop., *Grimmia pulvinate* (Hedw.) Sm., *Philonotis marchica* (Hedw.) Brid. and *Haplocladium* species showed broad-spectrum antifungal activity, followed by liverworts such as *Dumortiera hirsuta* (Sw.) Nees and *Pellia epiphylla* (L.) Corda. Ethanolic extracts have been shown to have greater activity than other solvents used (Shirzadian *et al*., 2009). Resolute antifungal activity of the moss *P. revoluta* against the fungus *viz. Fusarium moniliformae* (Sheldon), *Curvularia lunata* (Wakker) Boedijn and *Helminthosporium turcicum* (Pass). Leonard & Suggs. The authors assessed the fresh weight and colony diameter of test organisms under the effect of various concentrations of extracts. All the extracts showed remarkable inhibitory activity against the tested fungi. The maximum fresh weight and colony diameter were found at low concentrations, and the minimum was found at high concentrations of *P. revoluta* Bosch & Sande Lac. extract by (Deora *et al*., 2010).

In vitro, the antibacterial activity of the bryophytes was assessed using agar-well diffusion assays. Dichloromethane and methanol were used for the preparation of the extracts, and the three bacterial strains were used to assay the activity. The inhibition of bacterial growth was compared with that of tetracycline and ampicillin, which were used as positive controls, and solvents, which were used as negative controls. The extracts of *both A. wallichiana* (Lehm.) Grolle, *Targionia hypophylla* L. and *Plagiochasma intermedium* Lindenb. & Gottsche showed antibacterial activity against all the tested bacterial strains (Sawant *et al.,* 2010). Deliberated initial phytochemical analysis of the spike moss *S. inaequalifolia* (Hook. & Grev.) Five extracts, such as chloroform, ether, benzene, distilled water and ethanol, were sprayed on the plants, and secondary metabolites, such as tannins, sugars, steroids, catechins and phenolic groups, were found. These extracts had more antimicrobial potential against phenolic compounds. Three microbes, *viz. Staphylococcus aureus*, *Escherichia coli* and *Candida albicans* were obtained from Irudayaraj *et al*., (2010).

Marchantia polymorpha L. is likely to be a useful ingredient for the manufacture of environment-friendly biopesticides and antimicrobial agents (Gahtori *et al*., 2011). Bryophytes such as *Plagiochasma appendiculatum* L. and Aytoniaceae, *Conocephalum conicum* (L.) Necker (Conocephalaceae), and *Bryum argenteum* Hedw. (Bryaceae) and *Mnium marginatum* (With.) P. Beauv. These bryophytes were tested for their ability to fight several common bacteria that can cause burn infections (Singh *et al*., 2011). The 50% methanolic extract was obtained from some rare Himalayan bryophytes *viz. Fossombronia himalayensis* Kash, *Metzeria himalayensis*, *Sauchia spongiosa* Kashyap, *Wiesnerella denudata* (Mitt.) Steph., *Marcantia polymorpha* L., *Conocephalum conicum* (L.) Underw. and *Riccia fluitans* L. were used for thin-layer autobiochromatographic procedures for antifungal activity. Alcoholic (ethanol and methanol) and aqueous extracts of *Entodon nepalensis* Mizush and *Atrichum undulatum* (Hedw.) were assessed for their antibacterial activity against *Escherichia coli*, *Bacillus subtilis* and *Salmonella typhimurium* (Mishra *et al*., 2011). The antifungal activity of extracts from *Hyophilarosea* Williams, *Plagiochasmarupestre* (J. R. Forst. & G. Forst.) Steph and *Targioniahypophylla* L. are more potent against fungal strains such as *Aspergillus niger*, *A. flavus*, *Alternaria alternata*, *Phytophthora infestans*, *Trichoderma viride*, *Fusarium oxysporium*, *Penicillium expansum* and *P. chrysogenum* when compared to synthetic fungicides. The average concentrations required for this efficacy range from 2.5 mg/ml to 20 mg/ml (Alam, 2012).

The antifungal effects of *Hyophila rosea* Williams on *Aspergillus flavus* (Montagne) de Bary., *Alternaria alternate* (Fries) Keissler and *Phytophthora infestans* (Montagne) de Bary were studied by using the disc diffusion method. It has been reported that the chloroform extract of *P. infestans* has the highest antifungal activity (Alam, 2013).

Conscious comparative antimicrobial activity of *Reboulia hemisphaerica* (L.) Raddi was detected by agar well diffusion. The activity was assessed by using phenolic compounds and methanolic extracts. Gram-negative bacteria were less sensitive than Gram-positive bacteria, while fungal strains were less sensitive (Sharma *et al*., 2013). The antimicrobial activity of *Plagiochasma articulatum* L. and *Fissidens bryoides* Hedw. against bacterial strains *viz. Agrobacterium tumefaciens*, *Streptomyces scabies* and *Xanthomonas citri* were obtained (Deora and Rathore, 2013).

The effects of boiled and cold-water crude extracts of *Bryum capillare* on *Drechslera maydis,* a plant pathogenic fungus, were investigated. The results showed that the boiled water extract had strong antifungal activity against the test fungi (Deora and Guhil, 2014). Two liverworts, *Plagiochasma appendiculatum* L. and *Pellia endiviifolia* (Dicks.) Dumort showed strong biochemical activity in its antioxidant defence system and may be active against microbes. Both liverworts showed antifungal effects against the tested fungus even at extremely low concentrations. *Plagiochasma* species were shown to always have more guaiacol peroxidase and catalase activities than *Pellia* species (Sharma *et al*., 2014). The presence of different kinds of biologically active substances, *viz*. Flavonoids, terpenoids, alkaloids, glycosides, saponins and sterols and their inhibitory effects on the growth of *Xanthomonas citri* and *Pseudomonas syringae*, were studied using the spread plate and agar well diffusion technique for colony counting and zone of inhibition, respectively by Deora (2015).

Studied three fungal species, *Aspergillus niger* van Tieghem and *Fusarium solani* (Mart.) Sacc. and *Trichoderma viride* Pers. were used to assess the antifungal activity of *Actinium clarum* Mitt. and *Hyophila spathulata* (Harv.) A. Jaeger. also preferred acetone, chloroform, distilled water, ethanol and methanol as our five extraction solvents. The disc diffusion technique was used for the activity (Bishnoi *et al*., 2015). The antifungal effects of the aqueous crude extract of *Bryum cellulare* against the fungus *Curvularia lunata,* the causal organism of leaf spot in wheat and *Drechslera maydis* and the causal organism of leaf blight in Zea *mays* were assessed using pour plate techniques. According to the conclusions, the *Bryum cellulare* concentrations at which the colony diameter and fresh weight of the test organism were determined to be highest at lower concentrations and minimum at higher concentrations were determined (Deora and Guhil, 2015).

Antifungal activity of *Philonotis revoluta* Bosch & Sande Lac. by the hanging drop method. The methanol extract of mosses exhibited a greater effect on spore germination of the fungus *Helminthosporium turcicum* than the acetonic extract (Deora and Suhalka, 2016). The effectiveness of bryophytes as a substitute for synthetic drugs was tested by determining their biochemical and antimicrobial potential. The antibacterial and biochemical properties of the moss *Hydrogonium gracilentum* (Mitt.) P. C. Chen and two liverworts, *Reboulia hemisphaerica* L. and *Marchantia palmata* Reinw., Nees & Blume, were assessed under laboratory conditions. Both the ethanolic and acetonic extracts of these mosses and liverworts inhibited the growth of *Bacillus cereus*, *Pseudomonas aeruginosa*, *E. coli* and *Erwinia chrysanthemi* on agar plates (Kandpal *et al*., 2016). The antimicrobial activity of epiphytic mosses such as *Pogonatum microstomum* (Schwaegr.) Brid and *Pallavicinia lyelli* (Hook), *Fissidens brevinervis* (Broth.) against penicillin-resistant bacteria. Various solvents, such as acetone, ethyl acetate and distilled water, were used for extraction. All the extracts showed remarkable antibacterial activity against all the tested bacterial strains (Williams *et al*., 2016).

The fungal toxicity of the acetonic, methanolic and aqueous extracts of *Riccia gangetica* Ahmad was evaluated. Extracts were prepared in acetone, methanol and aqueous solution at concentrations ranging from 10-100. The fungal toxicity of the extract was measured by determining the percentage of spore germination, hyphal length and inhibition using the hanging drop method. The maximum antifungal activity was noted in the 100% methanolic extract, and the other extracts exhibited moderate to negligible antifungal activity (Deora and Suhalka, 2017). The antimicrobial activity of the two bacterial strains was evaluated against bryophytes *viz. Asterella angusta* (Stephani) Pande, K.P. Srivast. & Sultan Khan, *Plagiochasma articulata* Kashyap, *Anthoceros erectus* Kashyap, *Cyathodium tuberosum* Kashyap and *Targionia hypophylla* L. The highest antibacterial activity was reported for *Targionia hypophylla* L. (Kadam, 2017).

Aqueous extracts of *Hydrogonium arcuatum* (Griff.) Wijk. Marg. and *Hydrogonium consanguineum* (Thwait. and Mitt.) Hilp. The antifungal activity of these extracts against the test fungus *Alternaria solani* was studied, and *Hydrogonium consanguineum* extract was found to be more effective than *H*. arcuatum against *Alternaria solani* mycelial development (Deora and Deora, 2018). The antibacterial potential of *Pogonatum microstomum* Schw. against *Streptococcus hemolyticus* (Lubaina *et al*., 2018). Deliberation of *Atrichum undulatum* (Hedw.) *P*. gingival is an alcoholic and aqueous extract for antimicrobial activity against *Aspergillus fumigatus, Fusarium oxysporum* fungus, *Staphylococcus aureus*, *E. coli*, *Salmonella typhi*, *Proteus mirabilis* and *Bacillus mycoides* bacteria. The agar well diffusion technique was tested on two bacterial strains from the bryophytes *viz. Anthoceros erectus* Kashyap, *Asterella angusta* (Stephani) Pande, K. P. Srivast. & Sultan Khan, *Cyathodium tuberosum* Kashyap, *Plagiochasma articulata* Kashyap and *Targionia hypophylla* L. by Saxena and Yadav (2018). The antimicrobial properties of these materials are due to the presence of secondary metabolites. The study showed that bryophytes exhibit antibacterial activity because of their good potential for the production of drugs (Sangeetha, 2019).

Informed that *Bryum capillare* Hedw., *B. cellulare* Hook. and *B. argenteum* Hedw. an extract of methanolic extract was present in quercetin and showed antifungal activity against *maydis* but not *B. argenteum* Hedw. The methanolic extract was the most effective against *Drechslera maydis,* followed by *Bryum cellulare* Hook. and *Bryum capillare* Hedw (Deora and Guphil, 2020). Aqueous extracts of *Targionia indica* Kash., *Cyathodium tuberosum* Kash. and *Anthoceros erectus* Kash. was used to synthesize antimicrobial activity silver nanoparticles from *ex-situ* conserved bryophytes in coastal regions of the Raigad district. In the pharmaceutical sector, particular nanoparticles are used on a large scale to prevent fungal infections due to their antifungal properties (Khamgal *et al*., 2021). Furthermore, all the characteristics of the bryophytes and their biomolecules, molecular formulas and medicinal uses from the reported literature are summarized in Table [1] and Table [2]. These findings can significantly support the fundamental idea of the medicinal uses of bryophytes.

Conclusion

This summary reviews the structural evolution of antibacterial and antifungal properties in bryophytes, focusing on their bioactive substances and secondary metabolites relevant to medicinal applications. Research on the pharmacological effects and phytochemical profiles of bryophytes remains sparse due to limited sample availability for extensive bioactivity analysis.

Bryophytes, the nonvascular plants, possess antimicrobial agents *viz*. Riccardin A, Marchin A, Lunularin, terpenoids, acetogenins, Marchin E and Bis-Bibenzyl, found in species such as *Marchantia polymorpha*, *Mnium marginatum*, *Brachythecium* rutabulum, *Frullania muscicola*, *Marchantia papillata*, *Pogonatum aloides*, *Pallavicina lyellii* and *Dumortiera hirsuta*. These compounds can function as antibiotics with various modes of action, including interference with cell wall synthesis, membrane integrity, nucleic acid synthesis, ribosomal function and folate synthesis.

Historically, bryophytes have been used medicinally in Asia for ailments like skin diseases, wounds, and cardiovascular issues. Recent research has begun exploring their broader therapeutic potential. Notable studies have examined bryophytes' antimicrobial properties, including their effects on larvae and honeybees and their potential as antimicrobial and antioxidant agents.

Post-1970, significant research in India highlighted the biochemical aspects of bryophytes, with over 200 species showing positive antimicrobial results. Studies focus on the use of organic solvents, phytochemical analysis, and antimicrobial activity, revealing that some Indian species of *Plagiochasma* and *Pellia* outperform synthetic drugs. Thalloid liverworts and dominant moss species have also been tested for antibacterial and antifungal activity. Research on bryophytes like *Sphagnum* and *Jungermannia* has shown anticancer properties, while others are used for treating burns and various medical conditions.

Future drug discovery will leverage phytochemical analysis to explore bryophytes' biological activities, including their potential to treat liver disease, skin disorders, and cancer. Bryophytes like *Conocephalum conicum*, *Marchantia polymorpha*, *Reboulia hemisphaerica*, *Bryum argenteum*, *Climacium dendroides*, *Funaria hygrometrica*, *Rhodobryum roseum* and *Sphagnum* sp. are promising for treating liver diseases, while *Asterella angusta*, *Cratoneuron filicinum*, *Jungermannia fauriana*, *Sphagnum palustre* and *Marchantia papillata* show potential for cancer treatment, inflammation reduction and heart disorder management (Bandyopadhyay and Dey, 2022). The Marchantin group, Ohioensin group, Bibenzyl group, Riccardin group and Pallidisetin it is possible these compounds could be expanded into potential therapeutics, but further research is needed to confirm their efficacy.

Conflicts of Interest

The authors declare no conflicts of interest.

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