International Journal of Botany Studies
www.botanyjournals.com
ISSN: 2455-541X
Received: 18-08-2024, Accepted: 17-09-2024, Published: 02-10-2024
Volume 9, Issue 10, 2024, Page No. 8-15

A study on ethnomedicinal uses and phytochemistry of bryophytes; especially focusing on anti-cancer properties

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Abstract
Bryophytes, a relatively overlooked group of terrestrial plants, have long been utilized in traditional medicine for their therapeutic properties. Their unique morphology and physiology have made them valuable to various indigenous cultures for treating a wide range of health conditions. Bryophytes are noted for their diverse bioactive compounds, including alkaloids, flavonoids, terpenoids, and polyphenols, which contribute to their medicinal efficacy. These plants exhibit several therapeutic effects, such as anti-inflammatory, analgesic, antimicrobial, and antifungal properties. Research indicates that bryophytes possess a broad spectrum of pharmacological activities, including antioxidant, antitumor, and immunomodulatory effects. Extracts and isolated metabolites from bryophytes have demonstrated cytotoxicity against various cancer cell lines, with some compounds showing selective action against cancer cells. Additionally, the high antioxidant content of bryophytes may offer protective benefits against oxidative stress-related diseases, such as cancer, diabetes, and cardiovascular conditions. This review aims to provide a thorough examination of the current literature on the phytochemical composition, therapeutic uses, and pharmacological activities of bryophytes.

Keywords: Bryophytes, phytochemical, anti-cancerous, anti-apoptotic, cytotoxic activity, pharmacological activity

Introduction

Bryophytes, commonly referred to as the 'amphibians of the plant kingdom,' occupy an intermediate taxonomic position between thallophytes (algae) and pteridophytes. This group is subdivided into three primary categories: Bryophyta, which includes approximately 14,000 species of mosses; Marchantiophyta, comprising around 6,000 species of liverworts; and Anthocerotophyta, which consists of approximately 300 species of hornworts (Hallingbäck, T., & Hodgetts, N. (2000) [20]. Status Survey and Conservation Action Plan for Bryophytes. Mosses, Liverworts, and Hornworts. IUCN, Gland, Switzerland., n.d.). Bryophytes are found in a diverse range of habitats globally, from arid deserts to frigid polar regions, though they are typically absent from marine environments. As photosynthetic, non-vascular plants, bryophytes are notably characterized by their lack of true roots, stems, and leaves. Instead, they possess simple structures called rhizoids, which anchor the plants to the substrate and facilitate the absorption of water and nutrients from the surrounding environment (Glime, 2007) [16]. Ecologically, bryophytes play a significant role by providing a buffering system for other plant species. Their utility extends to various applications, including serving as indicators of environmental changes, controlling soil erosion, detecting heavy metals in air pollution, acting as aquatic bioindicators, and assessing levels of radioactivity (Harris, 2008) [21]. Additionally, bryophytes provide materials for seed beds, fuel, medicinal substances, and food sources. They also contribute to nitrogen fixation, promote moss gardening, aid in waste treatment, and are used in construction, clothing, furnishing, and packaging. Moreover, bryophytes facilitate genetic engineering and enhance soil conditioning and cultivation (Glime, 2007) [16]. Bryophytes are recognized for their ability to accumulate soluble phenylpropanoids, including flavonoids and lignans. Flavonoids, a class of secondary plant metabolites, are known for their antioxidant and UV-protective properties. Lignans, another type of secondary metabolite, are structurally related to lignin and exhibit antitumor and anti-inflammatory effects (Xie *et al*., 2010). Research indicates that bryophytes can synthesize a diverse range of flavonoids and lignans, and the accumulation of these compounds may contribute to their environmental adaptation (Charron & Quatrano, 2009) [10]. For example, certain bryophytes have been observed to accumulate flavonoids in response to UV radiation, which can damage their delicate tissues (Asakawa *et al*., 1982) [4]. Additionally, some bryophytes produce lignans as a defensive strategy against herbivores and parasites. Bryophytes represent a diverse and complex group of plants capable of synthesizing a broad spectrum of phytochemical compounds. Mosses, for instance, produce polyphenolic compounds such as catechin and quercetin, in addition to terpenoids and alkaloids. Liverworts, another subgroup of bryophytes, are known for their production of various acyclic and cyclic diterpenes, as well as bis(bibenzyls) and other phenolic compounds (Asakawa, 2007; Asakawa *et al*., 1982) [3, 4]. These phytochemicals exhibit a range of biological activities and fulfill various ecological functions. For example, the polyphenolic compounds in mosses may possess antioxidant and antimicrobial properties, while the diterpenes in liverworts may function as insecticides or provide protection against UV radiation. The alkaloids synthesized by hornworts may exhibit antimicrobial or insecticidal properties, whereas the phytosterols present in these plants may contribute to growth and development (K. Kumar *et al*., 2000; P. Kumar & Chaudhary, 2010) [33, 34]. The extensive diversity of phytochemical compounds in bryophytes underscores their remarkable adaptability to diverse environmental conditions. This diversity not only highlights the ecological importance of bryophytes but also suggests their potential for applications in medicine, agriculture, and other fields

(Lubaina *et al*., 2014) [39]. Future research should focus on further elucidating the mechanisms behind their phytochemical synthesis and exploring novel applications of these compounds in various industries.

Methodology

A comprehensive literature review was undertaken to investigate the pharmacological properties, phytochemistry, and therapeutic potential of bryophytes. This review involved an extensive analysis of scientific articles and journals sourced from esteemed databases such as Scopus, Web of Science, PubMed, Google Scholar, ScienceDirect, ResearchGate, and Dlad4. The search utilized specific terms, including "antitumor," "anticancer," "antiproliferative," and "therapeutic uses of bryophytes." To assess the toxicity of various bioactive compounds, electronic databases such as ProTox-II, IMPPAT, and Molinspiration were consulted. Table 1 summarizes the ethnomedicinal properties of bryophytes, while Table 2 outlines the anticancer compounds identified in these plants, including CID (Chemical Identifier) numbers as listed in PubChem. Figure 2 illustrates the molecular structures of these anticancer bioactive compounds, and Table 3 presents their toxicity profiles.

Bryophytes and Ethnobotany

Bryophytes, including mosses, liverworts, and hornworts, have been used in traditional medicine, cuisine, and crafts for centuries. Despite their historical use, scholarly attention to their ethnobotanical applications, especially in healthcare, has been limited, likely due to a perception of minimal impact on human health. Approximately 136 bryophyte species are documented for ethnobotanical use globally. This review highlights their medicinal applications in Chinese, Indian, and Native American traditions. Factors such as low biomass production and species identification challenges contribute to their limited medicinal use. However, in regions with substantial bryophyte biomass, such as colder and tropical climates, their use is more prominent. For example, traditional Chinese medicine utilizes around 40 bryophyte species, with *Conocephalum conicum* and *Marchantia polymorpha* used in ointments for skin conditions. *Sphagnum teres* treats eye disorders, and *Haplocladium microphyllum* is used for respiratory and urinary conditions. *Polytrichum commune* has antipyretic, diuretic, and hemostatic properties, while *Plagiochasma appendiculatum* is used in India for skin ailments. Bryophytes, such as those producing Sphagnol, are also recognized for treating skin disorders. Their role in forming Shilajit, a traditional medicine, underscores their healing properties. Ethnobotanical research has significantly contributed to discovering new pharmaceutical agents. For instance, *Fontinalis antipyretica* exhibits antiproliferative and antimicrobial activities, while *Polytrichum juniperinum* shows antibacterial properties. Additionally, *Marchantia polymorpha* has antiviral and antifungal activities

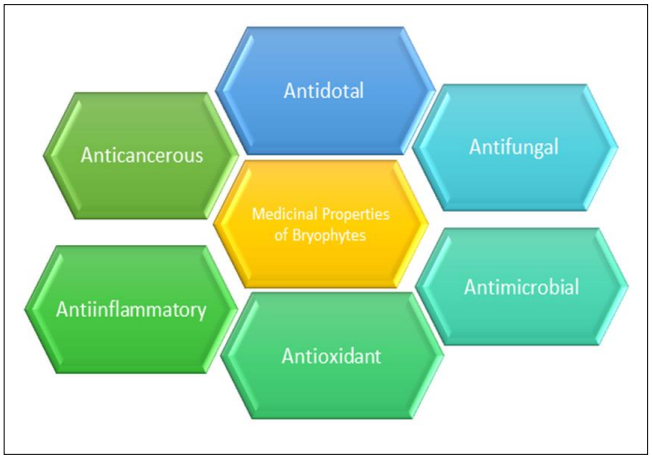

Fig 1: Medicinal Usage of Bryophytes

Table 1: Summary of different phytochemicals and therapeutic activities of bryophytes

S.no	Species name	Family	Bioactive compound	Pharmacological activity	Reference
1	*Polytrichum pallidisetum*	Polytrichaceae.	Pallidisetin A, Pallidisetin B	Anti-inflammatory, cytotoxic agent	(Ivanova *et al*., 2007) [24]
2	*Bazzanianovaezelandiae*	Lophoziaceae.	Naviculyl caffeate	As cytotoxic agent	(Burgess *et al*., 2000) [9]
3	*Taxiphyllum taxirameum*	Pylaisiaceae	phenols	Homeostasis and wound healing	(Asakawa *et al*., 2013) [5]
4	*Fissidens nobilis*	Fissidentaceae	Terpenoids	Hairfall treatment	(Azuelo *et al*., 2011) [6]
5	*Rhodobryum roseum*	Bryaceae	Phenols and Flavinoids	Nervous disorder treatment	(G. Pant & Tewari, 1989) [43]
6	*Targionia hyphophylla*	Targioniaceae	Alkaloids	Antibacterial	(Rycroft *et al*., 2001) [45]
7	*Philonotis sp*	Bartramiaceae	Triterpenoid, saponins	Antidotal, antipyretic agent	(Asakawa, 2007) [3]
8	*Plagiochasma intermedlum*	Aytoniaceae	Neomarchantin A, Riccardin C	Antifungal activity	(Xie *et al*., 2010)
9	*Reboulia hemisphaerica*	Aytoniaceae	Marchantiaquinone	Antifungal and anti-platelet medication	(Wei *et al*., 1995)
10	*Hypnum cupressiforme*	Hypnaceae	cupressuflavone	Used as an antimicrobial and antifungal agent	(Veljić *et al*., 2009)
11	*Rhodobryum giganteum*	Bryaceae	P-hydroxycinnamic acid,7–8 dihydroxy-coumarin	Antidiuretic properties and cardiovascular properties	(Ding, 1982) [13]
12	*Targionia sp.*	Targioniaceae	11-dihydrodehydrocostuslactone	Antifungal agent	(Remesh & Manju, 2009) [44]
13	*Marchantia palmate*	Marchantiaceae	Marchantin A	To treat Boils and abscesses.	(G. Pant & Tewari, 1989) [43]
14	*Radula sp.*	Radulaceae	Perrottetin E, Radulanin K	Antimicrobial activity	(Veljić *et al*., 2009)
15	*Herbertus aduncus*	Herbertaceae	(-)-Alpha-herbertenol, (-)-beta -herbertenol	Antifungal agent	(Xie *et al*., 2010)

16	*Pellia endiviifolia*	Pelliaceae	Sacculatal, Polygodial, Eudesmanolides,	Skin disorder, Microbial infection	(Asakawa *et al*., 2013) [5]
17	*Frullania muscicola*	Frullaniaceae	3-hydroxy-4'-methoxybibenzyl	Antifungal activites	Lou *et al*., 2002) [38]
18	*Riccardia marginata*	Aneuraceae	2,4,6-trichloro-3-hydroxy bi-benzyl	Anti-microbial activity	
19	*Radula complanate*	Radulaceae	3,5-dihydroxy-4-(2, 3-epoxy-3-methyl butyl) bibenzyl	Antimicrobial activity	(Veljić *et al*., 2009)
20	*Chandonanthus hirtellus*	Scapaniaceae	Alpha -bisabolene, anastreptene, chandonanthone, setiformenol and barbylicopodin	Antioxidant properties	(Komala *et al*., 2010) [32]
21	*Reboulia hemisphaerica*	Rebouliaceae	Benzoquinone	Hemostasis promotes wound healing.	(Wei *et al*., 1995)
22	*Frullania tamarisci*	Frullaniaceae	Tamariscol, frullanolide	Antiseptic activity	(Lou *et al*., 2002) [38]
23	*Cratoneuron filicinum*	Cratoneuronaceae	Terpenoids, acetogenins	Cardiovascular disease	(G. Pant & Tewari, 1989) [43]
24	*Philonotis Fontana*	Philonotaceae	Alcohol, amides, aromatic amines	Treat heat burns.	Remesh & Manju, 2009) [44]
25	*Oreas martina*	Aneuraceae	Glycosides, fatty acids, terpenoids	Treats epilepsy, haemostasis, and neurological diseases.	(Asakawa *et al*., 2013) [5]
26	*Ditrichum pallidum*	Ditrichaceae	Phenols, fatty acids	Treats for convulsions	(G. Pant & Tewari, 1989) [43]
27	*Weisia viridula*	Weisiaceae	Phenols	Antimicrobial activity	(Asakawa *et al*., 2013) [5]
28	*Plagiochasma appendiculantum*	Plagiochasmaceae	Alkaloids, flavonoids, carbohydrates, saponins	It heals skin disorders.	(Asakawa *et al*., 2013) [5]
29	*Dumortiera hirsuta*	Dumortiaceae	Riccardin D	As antibiotics and anticancer drugs.	(Azuelo *et al*., 2011) [6]
30	*Leptodictyum riparium*	Hypnaceae	Phenolic compounds	It is used to treat uropathy.	(G. Pant & Tewari, 1989) [43]
31	*Rhodobryum roseum*	Bryaceae	Flavonoids and phenols	Used to treat cardiovascular diseases and nervous disorders.	(G. Pant & Tewari, 1989) [43]
32	*Fissidens nobilis*	Fissidentaceae	Terpenoids	Treatment of hair loss	(Azuelo *et al*., 2011) [6]
33	*Taxiphyllum taxirameum*	Pylaisiaceae	Phenols	Haemostasis, external wound therapy	(Asakawa *et al*., 2013) [5]
34	*Mnium cuspidatum*	Mniaceae	Saponarin, flavonoids	used to treat nose bleeding	(G. Pant & Tewari, 1989) [43]
35	*Marchantia polymorpha*	Marchantiaceae	Marchantin E, Marchantin A	Anticancer, antipyretic, and antibacterial activity	(Beike *et al*., 2010, 2010) [7]
36	*Marchantia papillate*	Marchantiaceae	Bibenzyl, Riccardin C, Fatty acids, steroids	Anti-inflammatory, treat inflammation caused by fire, and antibacterial, treat blisters.	Karpiński& Adamczak, 2017) [28]
37	*Marchantia linearis*	Marchantiaceae	Flavonoid	Antifungal agent	(Xie *et al*., 2010)
38	*Marchantia convoluta*	Marchantiaceae	Flavonoid	Antiviral (hepatitis B), anti-inflammatory, and cytotoxic	(Chen & XIAO, 2005) [11]
39	*Marchantia polymorpha*	Marchantiacea-e	Plagiochin E	Antifungal, macrocyclic bis (bibenzyl) against Candida albicans	(Xie *et al*., 2010)
40	*Marchantia paleacea*	Marchantiacea-e	Flavonoids, saponins	Antimicrobial activity	(Siregar *et al*., 2021) [49]
41	*Asterella angusta*	Asterellaceae	Alkaloids, coumarins, flavonoids	Antibacterial, antifungal agent	(Khurram *et al*., 2011) [29]
42	*Entodon myurus*	Entodontaceae	Entodonin	Antibacterial agent	(Singh *et al*., 2011) [48]
43	*Bryum argenteum*	Bryaceae	Bryomycin	Used as an Anti-fungal remedy	(Frahm, 2004) [15]
44	*Plagiochasma appendiculatum*	*Rebouliaceae*	Plagiochasmic acid	To treat boils, and blisters.	(K. Kumar *et al*., 2000) [33]
45	Haplocladium microphyllum	*Thuidiaceae*	haplocladin	To cure bronchitis, tonsillitis, pneumonia, and fever.	(Ding, 1982) [13]
46	Weisia viridula	Pottiaceae	weisiolide	Relieving cold and fever symptoms.	(G. P. Pant, 1998) [42]
47	*Trichosteleum papillosum*	Sematophyll-aceae	Trichostelone	Rheumatism	(Boom, 1996) [8]
48	*Timmiella sp.*	Pottiaceae	Timmielactone.	Anti-inflammatory	(E. S. Harris, 2008a) [21]
49	*Thuidium cymbifolium*	Thuidiaceae	Thuidine, Thuidiumol	To address burn injuries.	(E. S. Harris, 2008a) [21]
50	*Tetraplodon mnioides*	Splachnaceae	Tetraplodonin	For epilepsy, sedative, and stroke therapy	(E. S. Harris, 2008a) [21]
51	*Sphagnum magellanicum*	Sphagnaceae	Sphagnan	For surgical dressings and manufacturing of Diapers	(G. P. Pant, 1998) [42]

52	*Meteoriella soluta*	Pterobryaceae	Meteoriellin	It calms and may alleviate external, gastrointestinal, and lung bleeding.	(Ding, 1982) [13]
53	*Leucodon secundus*	Leucodontaceae	Leucodone,	Head, neck, and abdominal pain	(Negi, 2020) [41]
54	*Dendropogonella rufescens*	Cryphaeaceae	Dendropogone	Pulmonary and renal health, Diabetes-related vision problems, Post-delivery pain, appetite stimulant	(Hernández-Rodríguez & López-Santiago, 2022) [23]

Pharmacological activity of bryophytes

Anti-cancerous compounds

Bryophytes produce a wide range of secondary metabolites with significant biological activities, including cytotoxicity. Notably, bibenzyl compounds and their dimers, such as bis(bi)benzyls, exhibit diverse biological properties, including anti-cancer, antimicrobial, antioxidant effects, liver X receptor alpha (LXRα) activation, HIV prevention, and modulation of various enzymes like cyclooxygenase, lipoxygenase, tyrosinase, calmodulin, and microtubule polymerization. Secondary metabolites from bryophytes are recognized for their therapeutic potential, demonstrating potent radical scavenging, antimicrobial, and pro-apoptotic activities. Methoxylated bibenzyls, such as Brittonin A and Brittonin B from the liverwort *Frullania inouei*, show significant cytotoxicity with half-maximal inhibitory concentrations (ID50) between 11.3 and 49.6 μM against various human tumor cell lines, including KB, KB/VCR, K562, and K562/A02, and exhibit multi-drug resistance (MDR). Additionally, sesquiterpene lactones like eudesmanolides, germacranolides, and guaianolides from liverworts also show cytotoxic effects against KB nasopharyngeal carcinoma and P-388 lymphocytic leukemia cells. A variety of novel naturally occurring compounds from bryophytes exhibit significant cytotoxic and cytostatic properties. Prominent examples include 4-epiarbusculin, oxyfrullanolide, 8,α-acetoxyzaluzanin C, diplophyllin, epoxyfrullanolide, marchaintin A, riccardin B, and perrottetin E. Additionally, maytansinoid and 15-methoxyansamitocin P-3, derived from moss species, have shown notable antitumor activity

A variety of novel compounds derived from bryophytes demonstrate significant cytotoxic and cytostatic properties. Key examples include 4-epiarbusculin, oxyfrullanolide, 8,α-acetoxyzaluzanin C, diplophyllin, epoxyfrullanolide, marchaintin A, riccardin B, and perrottetin E. Additionally, maytansinoid and 15-methoxyansamitocin P-3, isolated from moss species, exhibit notable antitumor activity. Compounds such as Isoplagiochin A and B from *Plagiochila fruticosa* inhibit tubulin polymerization with IC50 values of 50 and 25 μg/ml, respectively. Lunularin from *Dumortiera hirsuta* shows moderate cytotoxicity against the HepG2 human liver cancer cell line with an IC50 value of 7.4 μg/ml and exhibits antimicrobial activity against *Pseudomonas aeruginosa* with a minimum inhibitory concentration (MIC) of 64 μg/ml. Plagiochin E from *Marchantia polymorpha* effectively reverses multidrug resistance and induces G2/M cell cycle arrest by down-regulating specific cell cycle genes, enhancing cytochrome c release, nuclear fragmentation, and metacaspase activation, thus promoting apoptosis. Cyclic bis-bibenzyl compounds from *Marchantia polymorpha*, including Marchantin A, B, and C, exhibit notable biological activities; Marchantin C shows cytotoxic effects against P388 leukemia cells and pro-apoptotic effects on human glioma A172 cells. Paleatin B, an acyclic bis-bibenzyl from *Marchantia paleacea var. diptera*, demonstrates cytotoxicity against KB and P-388 cell lines and inhibits DNA polymerase β and cyclooxygenase with an IC50 of 45.2 μM. Ansamitocin P-3, from *Claopodium crispifolium* and *Anomodon attenuatus*, exhibits significant toxicity against A-549 and HT-29 human solid tumor cell lines. Additionally, Diplophyllin, an ent-eudesmanolide from *Diplophyllum ablicans* and *D. taxifolium*, shows substantial anticancer activity against human epidermoid carcinoma.

The table 2 provides molecular structures, CID numbers, and corresponding bioactivities of these anticancerous compounds.

Table 2: List of Anti-Cancerous Compound of Bryophytes

Bryophytes Plant SPP.	Bioactive Compound	CID NO.	Medicinal uses	Reference
Polytrichum juniperinum	Ohioensin-A	442531	Anti-cancerous activity	(Zheng *et al*., 1989)
Dumortiera hirsute	Lunularin	181511	Anti-cancerous activity	(Asakawa *et al*., 2013) [5]
Diplophyllum spp.	Diplophyllin,	315677	Cytotoxic activity	(Asakawa *et al*., 2013) [5]
Porella spp.	Perottetianal A	13874392	Anticancer activity	(Dey & Mukherjee, 2015) [12]
	Porelladiolide	102117199	Anticancer activity	(Dey & Mukherjee, 2015) [12]
Plagiochila sp.	Plagiochilin A	10315867	Cytotoxic activity	(Asakawa *et al*., 2013) [5]
	4E- dodecadienoate	5565651	Anticancer activity	(Toyota *et al*., 1998) [50]
	Sacculatal	14285716		(Jones & Rose, 1975) [26]
	Poligodial	72503		(Toyota *et al*., 1998) [50]
Marchantia polymorpha L	Marchantin A	442710	5-lipoxygenase inhibitory activity	(Asakawa *et al*., 2013) [5]
	Marchantin B	5319271	5-lipoxygenase inhibitory activity	(Asakawa *et al*., 1982) [4]
	Marchantin C	5319272	Cell cycle arrest	(Dey & Mukherjee, 2015) [12]
	Marchantin E	5319274	Inhibit tubulin polymerisation	(Asakawa *et al*., 1982) [4]
	Plagiochin E	16757518	Reverse of multi drug resistance	(Shi *et al*., 2008) [47]
	Marchantin M	90667793	Apoptosis	(H.-P. Liu *et al*., 2012) [36]
Conocephalum conicum	Germacranolide-s	10825511	Anti-cancerous activity	(Asakawa *et al*., 2013) [5]
	Bicyclogermacre-ne	13894537		(Asakawa, 1990) [2]
Frullania sp.	Costunolide	5281437	Cytotoxic activity	(Kim *et al*., 1996) [30]
	Germacradienol	16667385	Cytotoxic activity	(Kim *et al*., 1996) [30]

Bazzania sp.	Cyclomyltaylyl-3-caffeate	101610238	Anticancer activity	(Hashimoto & Asakawa, 2000) [22]
	Viridiflorol	11996452	Cytotoxic activity	(Hashimoto & Asakawa, 2000) [22]
	Gymnomitrol	14109432	Anticancer activity	(Hashimoto & Asakawa, 2000) [22], (Scher *et al*., 2004) [46]
	5-Hydroxycalamenene	13993189	Anti-cancer activity	(Hashimoto & Asakawa, 2000) [22], (Scher *et al*., 2004) [46]
	7-Hydroxycalamenene	3015179	Cytotoxic activity	(Hashimoto & Asakawa, 2000) [22], (Scher *et al*., 2004) [46]
	Drimenol	3080551	Cytotoxic activity	,(Hashimoto & Asakawa, 2000) [22], (Scher *et al*., 2004) [46]
Pellia endivifolia	10,10'-Dihydroxyperrottetin E	10253626	Cytotoxic activity	(Ivković *et al*., 2021) [25]
	10'-Hydroxyperrottetin E	101712298	Cytotoxic activity	(Ivković *et al*., 2021) [25]
	Perrottetin E	10646095		(Ivković *et al*., 2021) [25]
Bazzania novaezelandiae	Naviculyl Caffeate	5471279		(Burgess *et al*., 2000) [9]
Clasmatocolea vermicularis	Diplophyllolide A	11053496		(Lorimer *et al*., 1997) [37]
Porella perrottetiana	Tulipinolide	5281504		(Komala *et al*., 2011) [31]
Chandonantus hirtellus	Anadensin	14707350		(Komala *et al*., 2011) [31]
Lepidozia reptans	Lepidozin G	162641043	Apoptosis and Mitochondrial membrane distrupt.	(Zhang *et al*., 2021)
Heteroscyphus tener	Isomanool	15923774	Cell cycle arrest	(Lin *et al*., 2014) [35]
Jungermannia faurian	Jungermannenone A	101751159	Cell cycle arrest	(Y. Guo *et al*., 2016) [19]
	Jungermannenone B	102465605	Apoptosis	(Y. Guo *et al*., 2016) [19]
Frullania inouei	Brittonin A	353077	Inhibition of proliferation.	(D.-X. Guo *et al*., 2010) [18]
	Brittonin B	46933838	Apoptosis	(D.-X. Guo *et al*., 2010) [18]
Plagiochila Fruticose	Isoplagiochin B	44134 469	Inhibition of tubulin polymerization	(Morita *et al*., 2009) [40]
	Isoplagiochin A	11026 227	Inhibition of tubulin polymerization	(Morita *et al*., 2009) [40]

Table 3: Assessment of Phytochemical Toxicity

S no.	Phytochemical Compound	Carcinogenicity	Immunotoxicity	Mutagenicity	Cytotoxicity
1	Ohioensin-A	Inactive	Active	Inactive	Active
2	Lunularin	Inactive	Inactive	Inactive	Inactive
3	Diplophyllin	Active	Active	Inactive	Inactive
4	Perottetianal A	Inactive	Inactive	Inactive	Inactive
5	Porelladiolide	Inactive	Active	Inactive	Inactive
6	PlagiochilinA	Active	Inactive	Active	Inactive
7	4E- dodecadienoate	Inactive	Inactive	Inactive	Inactive
8	Sacculatal	Inactive	Inactive	Inactive	Inactive
9	Poligodial	Inactive	Inactive	Inactive	Inactive
10	Marchantin A	Active	Active	Inactive	Inactive
11	Marchantin 8	Active	Active	Inactive	Inactive
12	Marchantin C	Active	Active	Inactive	Inactive
13	Marchantin	Inactive	Active	Inactive	Inactive
14	Germacranolide5	Inactive	Inactive	Inactive	Inactive
15	Bicyclogermacrene	Inactive	Inactive	Inactive	Inactive
16	Costunolide	Inactive	Active	Inactive	Inactive
17	Germacradienol	Inactive	Inactive	Inactive	Inactive
18	CyclomyltayIyl-3-caffeate	Inactive	Active	Inactive	Inactive
19	Viridiflorol	Inactive	Inactive	Inactive	Inactive
20	Gymnomitrol	Inactive	Active	Inactive	Inactive
21	*Hydroxycalamenene	Inactive	Inactive	Inactive	Inactive
22	7-Hydroxycalamenene	Inactive	Inactive	Inactive	Inactive
23	Orimenol	Inactive	Inactive	Inactive	Inactive
24	Naviculyl Caffeate	Inactive	Active	Inactive	Inactive
25	Diplophyllolide A	Inactive	Inactive	Inactive	Inactive
26	Tulipinolide	Inactive	Active	Inactive	Inactive
27	Anedensin	Inactive	Active	Inactive	Inactive
28	Lepidozin G	Active	Active	Inactive	Inactive
29	Isomanool	Inactive	Active	Inactive	Inactive
30	JungermannenoneA	Inactive	Active	Inactive	Inactive
31	JungermannenoneB	Inactive	Active	Inactive	Inactive
32	arittonin A	Inactive	Inactive	Inactive	Inactive
33	Brittonin 8	Active	Active	Inactive	Inactive
34	Isoplagiochin 8	Active	Active	Inactive	Inactive
35	Isoplegiochin A	Active	Active	Inactive	Inactive

Structure of secondary metabolites

The secondary structure of phytochemical compounds derived from bryophytes, along with their corresponding CID numbers, plays a crucial role in computational drug discovery and in silico analyses. The secondary structure refers to the three-dimensional conformation of a compound, which is vital for identifying potential binding sites and interactions with target proteins or enzymes. This structural information is essential for the development of new pharmaceuticals or the optimization of existing therapeutic agents. CID numbers serve as unique identifiers within the PubChem database, a key resource in drug discovery and development, enabling researchers to access detailed information about specific compounds. Accurate toxicity prediction is critical for evaluating potential safety concerns associated with a compound, thereby enhancing the drug development process and reducing the need for animal testing. These parameters are fundamental to virtual screening and molecular docking studies, providing essential data that supports the development and refinement of pharmaceutical agents.

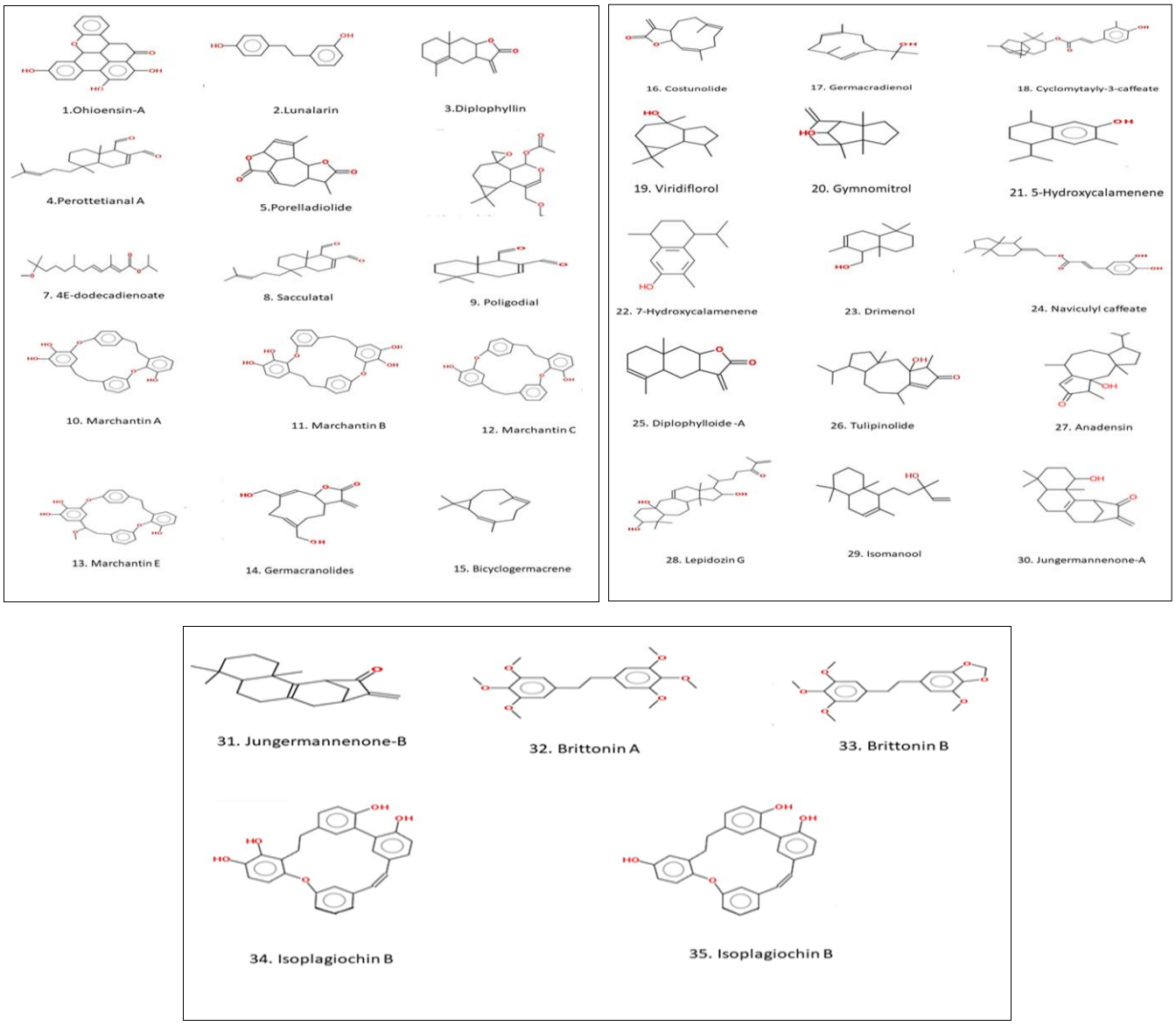

Fig 2: Secondary Structure of Phytochemical Compounds

Discussion and conclusion

Bryophytes are widely distributed globally, yet their chemical composition is not fully understood, with most research focusing on mosses and liverworts. These plants exhibit significant chemical diversity, including terpenoids, phenolics, biflavonoids, and stilbenoid-bibenzyls. Natural products and their derivatives are pivotal in drug discovery. This article provides an in-depth review of anticancer phytochemical compounds found in bryophytes, detailing their structures, SMILES formats, and functional properties to aid in virtual screening and molecular docking studies. It also addresses traditional topics like ethnobryology and summarizes the pharmacological properties of various phytochemicals. Despite progress, many phytochemicals in bryophytes remain unexplored for medicinal use. Effective methods for extracting, analyzing, and confirming these compounds, including their therapeutic and bioactive properties, are crucial for future drug development. This includes in-silico drug design techniques and exploring novel bibenzyl compounds for advancing complementary medicine and developing nutraceuticals.

Author contributions: PP: Conceptualization, Investigation, Validation, Writing—original draft. SR and

PJ: Conceptualization, Data curation, Validation. SC: Conceptualization, Investigation, Formal analysis, Supervision. All authors read and approved the submitted version.

Acknowledgments: The authors would like to thank the Department of Botany, Soban Singh Jeena University, S.S.J. Campus, Almora (Uttarakhand), India, for providing the facility and space for this research work.

Conflicts of Interest: The authors declare no conflict of interest.

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