Review Article

Bryophytes as Green Brain: Unique and Indispensable Small Creature

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ABSTRACT

Bryophytes are considered as the first green plant to develop during the evolutionary process and successfully establish themselves in an always varying environment. However, their utility is relatively not well known to most of the people. Bryophytes influences a number of ecosystem processes and have been used in different fields, like: horticulture, bio-monitoring, forest dweller, antimicrobial activities, etc and are being increasingly recognized around the world for multifarious applications.

Keywords: Antimicrobial activity, bryophytes, biomonitors, desiccation, forest dweller.

INTRODUCTION

Beginning with the statement, "Bryophytes grows where other plants can't." It is difficult to control because they will grow in extreme situations where vascular plants including turf grasses cannot. In bryophytes such studies are scarce. They form an important part of the Himalayan scenario; the percentage of occurrence of these small creatures in India is quite higher than that of any other plant group by about 27.5% of world mosses [1]. These are the largest group of land plants, which number about 25,000 different species and have wide distribution. As mentioned by several workers that Indian Himalayas are rich in bryoflora and India is one of the nation of South Asia and with in the country which is known as treasure house of bryophytes. These are primitive plants that have changed little over the course of history. Fossil records date the appearance of bryophytes 350 million years ago[2]. They are believed to have originated from filamentous (thread-like) green algae. Most are found in areas, which are humid and damp with a cold to moderately warm climate (Figure 1).

Figure 1: *Rhodobryum* sp. growing in natural habitat

They can withstand being frozen in snow without damage. During dry weather they appear dead but will regain normal function when moisture is available. Bryophytes, the first plants to migrate from water to land are evolutionarily and ecologically significant. A part from these bryophytes plays an important role in mineral cycling in the forest covers. By trapping nutrients from the through fall before they ever reach the soil, bryophytes serve as nutrient filters. This leads us to ask their role in parceling out nutrients to the soil. Nitrogen is often a limiting nutrient for plant growth, especially in agriculture. Bryophyte crusts, along with nitrogen-fixing bacteria, can contribute considerable soil nitrogen. Saxena in 1981[3] reported that, Cyanobacteria behave symbiotically in Anthoceros, taking nitrogen from the atmosphere and converting it to ammonia and amino acids. The excess fixed nitrogen is released to the substrate where it can be used by other organisms. Harper and Marble also in 1988[4], found that, bryophyte crusts not only help protect soil from wind and water erosion, and provide homes for nitrogen-fixing organisms, but they facilitate absorption and retention of water as well.

FOREST DWELLER

The basic factors on which life depends are light, warmth, moisture and nutrients, which make the forest rich. Bryophytes holds about 10 times more water than its weight and acts as a natural sponge, a hydrologic buffer to help control the flow of water in forests. They absorb water like sponges. Moisture from fog and rain is collected by them growing on branches in the canopy, tree trunks, and the ground. Consequently, they slow the rate at which water is lost from the forest ecosystem. The moss layer is important in determining soil characteristics, such as temperature and moisture[5,6], that in turn control carbon and nitrogen cycling within the rhizosphere[7,8]. In addition, they reduce erosion; processes that can wash away soil nutrients, damage the forest floor, and adversely affect the integrity of streams. Water stored in bryophytes evaporates slowly, and helps to maintain a humid environment in forests long after rainfall has ceased[9]. This is important not only for the growth of cryptogams, but also for plants. As evaporation of water from leaves exceeds rates of water transport from the roots, plants begin to close the small pores in their leaves that allow gas exchange. This conserves water at the expense of reduced photosynthesis. In the humid conditions created by cryptogams, plant leaves lose less water so they can keep their pores open longer and continue photosynthesis. They play a 'keystone' role in mineral cycling and regulation of microclimate in the canopy (Figure 2). It also provides nesting sites for marbled murrelet and red tree vole[10]. They may play an important role in nutrient cycling that is not yet fully understood. Bryophytes provide food and habitat for a host of invertebrates[11,12] and vertebrates. They are a perennial source of organic material and function as efficient filters for trapping sediments. Bryophytes are also a major component of the forest stream ecosystem, providing year-round habitat for a wide array of algal species, aquatic invertebrates, and amphibians.

Figure 2: Bryophytes as forest dwellers

DESICCATION POTENTIAL

Water is essential for life, but some organisms can survive desiccation for indefinite periods. This remarkable ability, called anhydrobiosis ("life without water"), is found across all biological kingdoms, including bacteria, fungi, animals and plants. Members of some taxonomic groups can survive desiccation at all stages of their life cycles and bryophytes (mosses) are just one of them. To be desiccation tolerant, a plant must be able to limit damage during both dehydration and rehydration, and survive in a dormant state for extended periods of time. Desiccation can reduce plants to 5-15 % of their normal hydration levels in a period of time ranging from minutes to days[13]. Mosses can survive being desiccated in minutes and resume normal function after addition of water in an hour or two[14]. These plants are believed to be constitutively prepared for desiccation with a focus on repairing damages upon recovery.

Desiccation tolerance is a widespread phenomenon[15-17]. In plants it is a frequent and characteristic feature of the vegetative cells of terrestrial bryophytes. A part from its intrinsic significance as an essential part of the basic adaptive strategy of the second most numerous groups of green land plants, desiccation tolerance in bryophytes (mosses) is of particular interest in a wider context for two reasons. First, in many bryophytes the switch from the fully hydrated metabolically active state to the dry, inactive "anhydrobiotic" state is quickly and fully reversible. Second, because of their ectohydric pattern of adaptation in relation to water, desiccation tolerance in bryophytes (mosses) can be studied without the complications introduced by stomata and a vascular system in vascular plants.

They are limited in the amount of moisture they can draw from rhizoids for metabolic requirements, and the need for free moisture for sexual reproduction, these constraints have resulted in a) becoming aquatic b) being confined to continually moist habitats or c) evolving the ability to loose water almost as rapidly as its surrounding environment does and then resume metabolic processes as moisture returns [18].

BIOMONITORS

Bryophytes readily absorb heavy metals without the regulation characteristic of their nutrient absorption. The ability of many bryophytes to sequester metals, while, remaining unharmed makes them good biomonitors. Mosses are outstandingly a successful group of cryptogams and so biologists have given much attention to use them as air quality monitor, particularly of metal concentration on account of their known sensitivity to pollutants. Mosses tolerate elevated levels of toxic elements and were for the first time used for biomapping by Ruhling and Tyler[19] and Goodman and Roberts[20]. Later on bryophytes were used as biological indicators of air quality[21]. They have the capacity to intercept, retain and accumulate pollutants. They have been used for ecological monitoring data in many countries including Scandinavia[22] and Netherland[23]. Because of their ability to sequester minerals yet remain unharmed, bryophytes are also good indicators of accumulated radioactivity[24-26].

The capacity of mosses to accumulate potentially toxic elements has led to their use as pollution monitor and when aerial deposition occurs, much of the accumulated metal is initially trapped in the form of particulate matter[27,28]. Since mosses take up nutrient mainly from the atmosphere[29], therefore a correlation was found between levels of an element in moss samples and in environment[30]. Therefore, the metal concentration in mosses is a valuable means of identifying air borne metal pollution and mapping the metal deposition[31]. Bryophytes are claimed to be good indicators of habitat quality and of the ecological function of habitats[32,33]. The lack of sclerenchyma makes bryophytes vulnerable to competitive exclusion by vascular plants and potentially suitable as early indicators of environmental change. Differences in metal uptake by mosses between sites will depend upon the array of metals present and reflect differences in adsorption affinities: adsorption of zinc and lead is greater than that of copper, which is greater than that of cadmium,[34]. High concentrations of zinc and lead may be due to dry deposition of metals dust spewed out from a number of automobiles[35] as well as from insecticides and pesticides used as growth promoters to increase agricultural productivity in rural sites. Fluctuation in distribution pattern could be due to different environmental factors in correlation with the distribution of emission sources. Furthermore, traffic density, proximity to other roads, precipitation, meteorological factors, seasons, time of sampling, and finally direction of prevailing wind may be the other cause (Figure 3).

For the investigations of air borne metal precipitation, although a wide range of plants and plant materials have been used, amongst them, angiosperms, grasses and ferns are not suitable for biomapping of air quality as they have well developed roots and absorb from soil[36]. Algae are misfit for air biomapping as they live in water. Monitoring by lichen is tough as sampling is difficult (samples are fragile). Through bryophyte monitoring, gathered spatial and temporal deposition patterns of metals could be used for environmental management[37]. One advantage of using bryophytes over other analytic methods is that bryophytes can easily be stored in an herbarium and analyzed later; in fact, historic records can be obtained by using old herbarium specimens because of the habit of most herbarium curators to store bryophytes in packets that protect them from additional pollution that might be present in the herbarium[38].

Bryo-monitoring is relatively inexpensive, employs passive and active acceptors, which imply temporally and spatial integration effects as well as bioavailability and give summarized effect of both paths of contamination mentioned and biomapping can be done by any one. They have a variety of means by which they can sequester substances that are toxic to many higher plants and animals[39]. These may be bound to cell walls through cation exchange, bound within cells in vesicles that protect the cellular metabolism from interference, located in electron-dense particles in cells or cell walls, or combined with other elements as insoluble compounds, thus rendering them harmless.

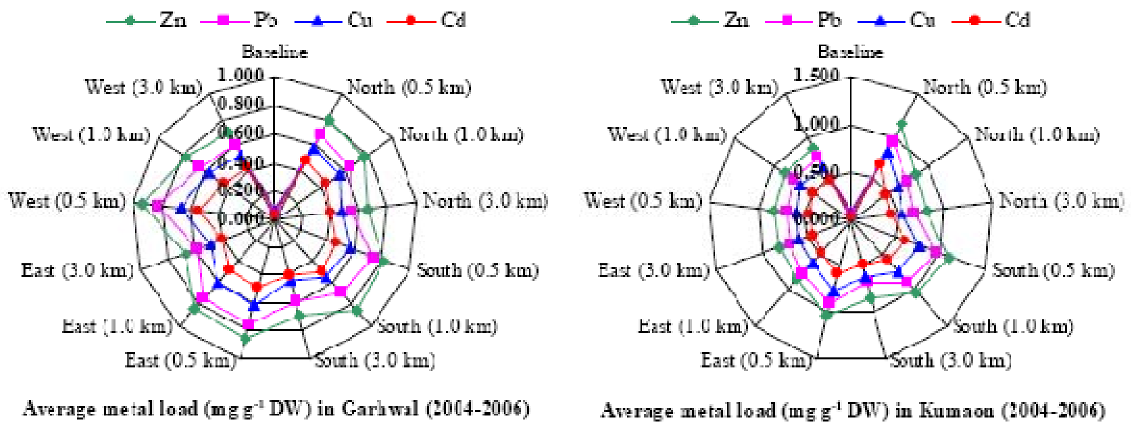

Figure 3: Assessment of metal accumulation in *Rhodobryum roseum* in Relation to atmospheric emission sources in Uttarakhand, India.

RETROSPECTIVE STUDY

Monitoring of metal precipitation using biomonitors like bryophytes is emerging as a potentially effective, more economical and reliable alternative biological tool. Biological monitoring for metals has several advantages over other ways for obtaining an integrated picture of metal precipitation levels. By this method it is possible in a less exacting way to reveal the area of high metal burdens to assess the level of metal input at different tropical levels and to obtain some relative estimates of the total aerial burden of metals[40]. Mosses preserved in herbarium are highly suitable for determining environmental pollution of the past. Since, mosses are largely dependent on the atmosphere for nutrient and moisture, it is quite safe to assume that the metal concentrations in samples correlate with atmospheric input as well as corresponding periods[41,42]. However, little has been done in regard to retrospective studies of metal content by bryophytes from India despite luxuriant bryophytic flora. Literature survey shows that there are few reports till date on metal precipitation profile of Kumaon and Garhwal areas of Uttarakhand as well as on retrospective metal data of any part of India[43].

Retrospective monitoring cannot be done by any instrument and here bryophytes come as tool through which it is possible to get the past metal load,[44] because of their slow death rate, decomposition and active absorption which make them ideal for retrospective studies[45]. Metals are efficiently retained by the bryophytes for a very long period even in a damaged plant, as they do not release them quickly after death. Since bryophytes absorb moisture and nutrients from air, their analysis represents the atmospheric metal load. Thus, their potential of being efficient active accumulators can be exploited in the studies based on the metal analysis of a portion of herbarium voucher specimens borrowed from different herbaria [46].

To reconstruct the past metal trend, an extensive literature review was done for planning and then a deposition scenario was developed. However, there are some uncertainties about exact location of voucher specimens, associated with the deposition scenario. To improve these scenario vouchers specimen were procured on loan for temporal record of historical metal deposition [46].

ANTI-MICROBIAL ACTIVITY

The use of bryophytes in herbal medicines has been common in China, India, and among Native Americans since ancient times. Numerous compounds, including oligosaccharides, polysaccharides, sugar alcohols, amino acids, fatty acids, aliphatic compounds, prenylquinones and aromatic and phenolic compounds occur in bryophytes, but few links have been made between any medical effects and specific bryophyte species or compounds[47]. Clinical research showed that an ether extract of *Rhodobryum giganteum*, used by peasants to cure angina, contains volatile oils, lactones, and amino acids. When given to white mice, the extract actually reduced oxygen resistance by increasing the rate of flow in the aorta by over 30% [48]. In the Himalayas, Indians use a mixture of moss ashes with fat and honey as a soothing and healing ointment for cuts, burns, and wounds[49]. They claim it has a soothing effect and heals wounds more quickly[50]. The antibiotic properties of Sphagnum have been discovered throughout the Northern Hemisphere. In Alaska, the Indians mix it with fat to make a salve[51,52]; in Britain it was used to treat boils[53]; the derivative sphagnol relieves the itch of a mosquito bite[54]; and it has been used for medicinal baths[55,56], but the small amounts of active substances put into an average bath are not likely to have any effect.

This group is least investigated among plants for bioactive molecules. Yet in nature they appear to be well protected against grazing and pathogens by there chemical constitutes. Some bryophytes such as the bog-moss *Sphagnum* and *Rhodobryum* sp. have well known antibiotic properties (Figure 4). Because of its absorbent and antiseptic properties it was used for dressing during World War I to make pillows for resting of wounded members for soldiers transported to hospitals from battlefields. Irish moss is a very useful herb as it has high content of nutrients. It contains vitamins A, D, E, F, and K. It has high content of iodine, calcium and sodium, which contributes in glandular system. It has high mucilage content, which makes it soothing to inflamed tissues and lungs and kidney problems[57]. Irish moss has been used externally to soften skin and prevent wrinkles. It purifies and strengthens the cellular structure and vital fluids of the system.

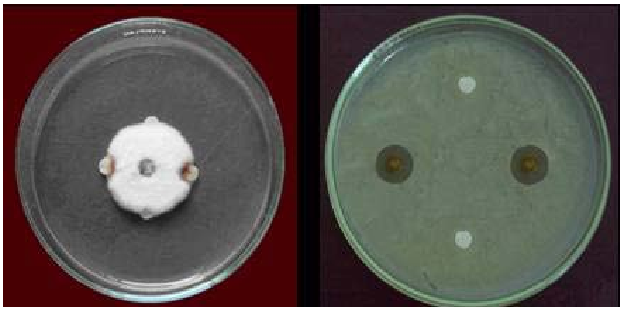

Figure 4: *Rhodobryum* sp. showing bioactivity against *Tilletia indica* (fungus) and *Xanthomonas oryzae* (bacteria).

Bryophytes have various therapeutic applications, which are currently used in the treatment. Liverworts do have champions, including herb list that value it for purported medicinal uses[58]. “Wort” means “Herb” and it is called the Herb of the liver because of an old belief, that it could cure liver disease and hydrophobia (rabies). Along this they have many diversified uses. There extract is not only a potent fungicide and bactericide, but also a weak biocide (stomach pest) against animal pests[59]. A chemical analysis of the moss *Rhodobryum gigantenum* indicates that it contains volatile oils, lactones and amino acids, which increase the rate of blood flow in arota by 30% [60].

Bryophytes are traditionally used in Chinese, Europe, North American and Indian medicine, to treat illness of cardiovascular system, tonsillitis, bronchitis, tympanitis, in skin diseases and burns. They also possess anticancer and antimicrobial activity due to their unique chemical constituents[61]. A few moss genera *Atrichum*, *Dicranum,Minium, Polytricum*, *Sphagnum, Porella*, and *Reboulia* prevent the soil erosion due to their trample - resistant structure and regenerative ability[62-64]. Compounds like polygodial from *Porella,* Norpiguisone from *Conocephalum conicum* and Lunularin from *Lunularia cruciata*, 4-hydro-3- methoxybibenzyl and a- and b- pininealloromadendrine from *Plagiochila stevensoniana* are useful as antimicrobial compounds[65,66] *Plagiochila fasciculate* shows inhibitory effect on P388 cells (Leucemia), *Herpes Simplex type 1*, *Polio type 1*, *Bacillus subtilis*, *Escherichia coli*, *Candida albicans, Trichophyton mentagrophytes* and *Cladosporium resinae*[67]. The antifungal activity of *Herberta aduncus* against *Botrytis cinerea, Rhizoctonia soloni, Pythium debaryanum* is well illustrated[68]. Members of *Fissidens* and *Polytrichum* were used as diuretic and hair growth stimulating drugs[69].

PLANT DISEASE MANAGEMENT

We have known about the ability of bryophytes to discourage insect pests for centuries, whereas, tracheophyte herbaria require ill-smelling moth balls to protect them from destruction by tiny beetles, bryophytes store safely with no such protection. Such safety suggests that bryophytes may contain some sort of natural pesticide[70]. Later, Davidson and coworkers[71] isolated the antifeedants ferulic and possibly m- or p-coumaric acid from a wall-bound fraction of the leafy shoots of *Brachythecium rutabulum* and *Mnium hornum* parts ignored by slugs that readily grazed the capsules. Asakawa has devoted his life to finding a wide variety of phenolic and other ill-tasting or lethal compounds in liverworts.

Several effective synthetic fungicides are available to control this disease[72]. However, due to increasing awareness of the ill effects of synthetic pesticides on human and animal health and also to the agrosystem, research efforts on alternative and more environmentally friendly methods of controlling pests and diseases have proliferated[73]. Beside biocontrol agents, the use of plant products in plant disease control seems to be a logical approach[74,75]. Farhm in year 2004[76] performed the first *in vivo* greenhouse experiments on the antifungal effects of bryophytes.

Study was carried out on the effect of different bryophytes bioactive agents (*R. roseum* and *M. polymorpha*) on the growth of two different plants i.e. tomato (*Lycopersicon esculentum* Mill.) and rice (*Oryza sativa* L.) against *Fusarium oxysporum* f. sp. *lycopersici* and *Xanthomonas oryzae* pv. *oryzae* respectively[77]. The overall impact of resistance inducers on disease suppression and growth dynamics varied greatly. It was also observed that efficacy of resistance inducers was dependent on the growth stages and compatibility with plants. Biocontrol agents (bryophytes extract) were excellent for growth promotion simultaneously with disease suppression in tomato and rice plants infected with *Fusarium* wilt and bacterial blight disease.

Bryophyte extract can easily be produced. It could therefore, be assumed that bryophyte extract would be a proper fungicide for third world countries. Farmers in regions rich in bryophytes (e.g., tropical montane regions) could even produce the extract themselves for little money, making them independent from having to purchase expensive products made in industrial nations.

ACCUMULATION OF CARBON IN BROPHYTES

There is growing consensus with in scientific community that increases in atmospheric methane (CH_4) and carbon dioxide (CO_2) are enhancing the earth's natural greenhouse effect. Because of the potential effects of these gases on global energy and future climate, there is an urgent need to quantify terrestrial sources and sinks of carbon. Understanding the rate of carbon accumulation has become more important in estimating the amount of carbon reserves and in terms of their relevance to climate change, CO_2 sequestration and global warming. Bryophytes are the primary and most important form of carbon storage in many ecosystems. They are a prominent feature of many forest and grassland types, where they can make an important contribution to carbon balance. Tropical montane rain forest, because of their complexity and variety of microhabitats, usually harbors a rich diversity of bryophytes. It has been estimated that these moss-dominated ecosystems (boreal forest and tundra) account for approxmately 35% of the world's reactive soil carbon pool[78]. This soil carbon has accumulated because of low soil temperatures and/or poor drainage or is locked up in permafrost[79]. Higher soil temperatures resulting from the disturbance of the moss layer or high latitude warming could increase decomposition rates, potentially changing these systems from being a sink to a source of CO_2 to the atmosphere[80,81] and creating a positive feedback to warming[82-85]. Similarly, bryophytes in the temperate forest and grasslands are thought to be an important carbon sink. Since the end of last glacial period, bryophyte (*sphagnum*) dominated served as a reservoir for terrestrial carbon. The long time-scales over which these carbon-rich bryophyte-dominated ecosystems have developed means that recovery following major disturbance require centuries or millennia. Bryophyte net primary production (NPP) comprises a significant fraction of the total NPP in boreal black spruce forests[86,87]. Bryophytes are important in both the hydrologic and carbon cycles of boreal ecosystems at large spatial scales[88].This unique property focuses on the importance of bryophyte-dominated ecosystems in global carbon because of enormous amount of carbon gets accumulated in bryophytes in all major ecosystems around the world.

MULTIFARIOUS UTILITY

Bryophytes are used in horticulture as soil additives, ornamental material for cultivation and for beautification of gardens. Peat is one of the most important soil conditioners and is commonly used in agriculture throughout the world. In Japan, mosses are used as ornamental plants in gardens, to give beauty and an ancient look to gardens by clothing tree trunks, rocks and stone[89]. Tray landscapes are a horticultural art in Japan in which several mosses like *Polytrichum commune*, *Leucobryum neilgherrense* and *Bartramia pomiformis* are used. Mosses are also helpful in soil stabilization and in retaining moisture. Some bryophytes are used in treatment of plant diseases such as *Phytophthora infestans* or *Alternaria solani*. In Bolivia and Peru, the alcoholic extracts from local rainforest liverwort species are used by farmers for plant protection. They are also used to cure fungal skin diseases of horses.

Bryophytes are used in construction and furnishing of houses in some parts of the world, especially in areas where woody pants are not available or very expensive. In some villages in the Himalayas, moss mats with shrubs, grasses and bamboo are used to make pharki, a kind of door placed at the opening of temporary huts. *Sphagnum* peat is combined with a binding matrix and to make "peatcrete" and "peatwood" used in construction. Peatcrete is a new, low cost construction product whose benefits are that it is easy to saw, nail into, mould into any shape, or carry to building areas that may be difficult to access.

In Japan, England, France, Finland, and the US, mosses have been used for decoration. In Japan, ornamental water flowers are made from dried *Climacium japonicum* and sold in markets. In India, mosses are used to make mattresses, cushions and pillows. In the Himalayas, people dry mosses and liverworts and make coarse powder from them to use as insect repellents in stored grains and other stored goods. In Germany, *Sphagnum* in combination with wool has been used for preparation of cheap cloth. In India, *Sphagnum* species, *Hypnum cupressiforme*, *Macrothamnium submacrocarpum*, *Neckera crenulata*, *Trachypodopsis crispatula* and *Thuidium tamariscellum* are used as packing material for transportation of apples and plums. Wet *Sphagnum* species and other mosses are used to pack around the roots of live plants for transportation from one place to another or as a mounting medium for epiphytic plants such as bromeliads and orchids. Bryophytes are often shunned by many insects or animals and are used as insect repellent in many villages, probably due to the presence of physiologically active organic compounds[90]. Sheet mosses such as *Hypnum* sp. have been common in decorations, especially nativity scenes, shop windows, and floral arrangements. Some are used for wreaths, crosses and ornamental water flowers[91].

Current studies are assessing the role of bryophytes serving as filters that remove nutrients from rainwater and store them. After death these nutrients are released in the substratum, making it rich. They are one of the least investigated groups of plants. So, it is an attempt to briefly examine some of the uses and application of this primitive group of lower plants and because of their multifarious uses and application bryophytes are known as "Green Brain".

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