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INVITED ESSAY

New Frontiers in Bryology and Lichenology

Recent Developments of Commercial Products from Bryophytes

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Abstract. *The antifungal and antifeedant activity of bryophytes is widely known, but mainly from in vitro studies. The first in vivo experiments have been performed at Bonn University. Alcoholic extracts of all twenty bryophytes used had an effect on a variety of crops infected with different fungi. Two liverworts showed systemic effects. Based on these results, commercial products from bryophytes have been developed and are sold in Germany. Additional field experiments using extracts derived from native bryophyte species were successfully completed in Peru and Bolivia. Bryophyte extract also has effects on human pathogenic fungi and may cure skin diseases, but currently are not sold for that purpose. However, a patent has been obtained to cure fungal infections of horses with bryophyte extract. This same extract shows antifeedant effects against slugs.*

Keywords. Bryophyte extracts, commercial products, fungicide, horticulture, natural product.

Ando and Matsuo (1984) gave a comprehensive account of the various uses of bryophytes, such as packing material, horticulture, decoration, medicine, antimicrobial, antifeeding, and antitumor effects. Although many commercially useful effects of bryophytes are known, there are few examples of economic use. Current economic uses include the use of peat in horticulture; *Sphagnum* for oil-spill cleanup, bricks, or flower pots (peatcrete); or the use of mosses for decoration of nativity scenes at Christmas time; and moss gardening. The economic use of bryophytes is found mainly in East Asia (China, Taiwan, and Japan) and is usually confined to horticultural uses such as cultivation of bryophytes for moss gardening. However, many of the known effects of bryophytes have so far not been applied in practice; for example the antimicrobial or antifeedant effect of bryophytes.

BRYOPHYTE EXTRACT AS FUNGICIDE

It is common knowledge that bryophytes are not infected by bacteria and fungi, even though most live in close connection to the forest floor or organic decomposing substrates. All living plants must protect themselves against microbial infections. Cormophytes have mechanical protection against infection through cuticle or bark. Bryophytes lack such a shield, but use chemical weapons that are part of their alternative poikilohydric life strategy. If a fungus spore falls on a bryophyte thallus or leaf, phenolic compounds are released when the surface is wetted, thus inhibiting spore germination. This is at least one important factor for the evolutionary success of bryophytes and the fact that they survived for more than 350 million years. Since the sixties of the last century, these

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FIGURE 1. Tomato plants infected by *Phytophora infestans*. Left control, untreated; both right plants treated with liverwort extract of different concentrations.

effects were tested in laboratories. An evaluation of the literature (Asakawa 1981, 1984, 1988, 1990; Asakawa et al. 1976, 1980; Banerjee & Sen 1979; Basile et al. 1999; Belcik & Weigner 1980; Castaldo-Cobianchi et al. 1988; Dikshit et al. 1982; Gupta & Singh 1971; Hayes 1947; van Hoof et al. 1981; Kamory et al. 1995; Lorimer et al. 1993, 1994; Madson & Pates 1952; Matsuo et al. 1982*a*; McCleary & Walkington 1966; McCleary et al. 1960; Pavletic & Stilinovic 1963; Wolters 1964) indicates that alcoholic and aquaceous extracts or isolated compounds of about 150 species of hepatics and mosses were used for agar plate tests. They showed antimicrobial effects against various groups of fungi and yeasts, as well as against gram positive and negative bacteria. However, all these were in vitro tests, and while all bryophytes were successfully tested at least against certain fungi and bacteria, and although the publications date back forty years, no in vivo tests have so far been performed. Thus the highly valuable knowledge of these nature products was never applied or used economically, probably due to the fact that bryologists are too much scientists and do not consider the value of their knowledge in practice. For that reason I encouraged the head of the Department of Phytopathology at the University of Bonn to perform the first in vivo greenhouse experiments on the antifungal effects of bryophytes.

For that purpose, different crops, such as tomatoes, green peppers, and wheat, were infected with plant diseases such as *Phytophora infestans*, *Botrytis cinerea*, and *Erysiphe graminis*. The greenhouse cultures were then treated with various concentrations of alcoholic extracts from 20 species of bryophytes from central Europe (Fig. 1). Principally, extracts from all bryophyte species showed effects, however in different degrees with regard to the species and concentration. Generally, extracts from liverworts had the highest biological activity, followed by peatmosses and true mosses (Tadesse 2002). Extracts of two liverwort species even showed systemic effects; plants sprayed prior to their inoculation with fungi were not affected by the fungus, while leaves that developed after the application of the liverwort extract were resistant.

This news was distributed by television, radio, and newspapers and raised a huge response, showing there is a need for such a product, especially in the alternative agriculture and gardening sectors. So far, the ecological agriculture industry is using heavy metal salts, such as copper sulfate, against fungus infection. This is problematic because the heavy metals accumulate in the soil. In contrast, bryophyte extract is easily and quickly degraded and is a natural product.

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. Bryophytes are also a sustainable resource. This idea was therefore suggested to the German Society for Technical Cooperation (GTZ), a federal institution for developing third world countries. They showed no response and after inquiries no interest. However, a private German development company, active in Peru, Red de Acción en Alternativas al uso de Agroquímicos (RAAA), motivated the Universidad Nacional de San Martin to test locally-produced bryophyte extract with local crops (coffee and tomatoes) and tropical plant diseases in the field within the project Manejo Ecológico de Plagas (MEP). Unfortunately, only mosses were used for extraction and not hepatics (generally more effective), however, the mosses did have positive results. A long term use in Peru could not be established because of the high cost of alcohol required for the extraction. In 2003, another test was started in Bolivia by the Unidad de Investigación y Desarollo FAN, financed by the biology students of the University of Bonn (with the profits from their summer party)! Extracts of *Frullania brasiliensis* and *Sphagnum* sp. were prepared according to the instructions from Germany and applied to cultures of tomatoes and potatoes. The cultures showed no visible affects of bacterial or fungal infections when compared with controls.

The introduction of bryophyte extract on the German market was even more difficult. A science magazine on a TV channel agreed to deal with the use of bryophyte extract, but only if a commercial product was available. The problem is, however, that officially no one is permitted to sell any of these natural products without admission under government regulations. Therefore I delivered bryophyte material for extraction to a company producing herb liquors under my own responsibility. This product was then sold by a chain of drugstores that sells alternative products. Later a company was founded, which produced and distributed the bryophyte extract. Upon the initiative of this company, the bryophyte extract received the necessary permission from the Federal Institute of Biology (Biologische Bundesanstalt). Within the first eight months, several thousand litres of bryophyte extract (Fig. 2) were sold, which is then diluted 1:100 for use.

The product is still extracted from plant material collected in the field, which limits the amount of extract. There is no ecological damage involved because the species used for extraction grows abundantly in semi-natural fir forests that are used for silviculture. However, the problem remains that the quantities of bryophyte extract needed by technological agriculture is so high that it cannot be covered by material from nature. Field experiments performed by the Institute of Ecological Agriculture of the University of Bonn revealed the need of several kilograms of bryophyte material for the amount of extract required per hectare. Nevertheless, application was made for a grant that would test the possibility of horticulturally growing bryophytes. This would have the advantage—along with better availability—of using clones with higher biological activity, perhaps even rare species with higher activity, and it would also avoid the cleaning of the material that is necessary before extraction. The culture tests should also include the peatmosses that are economically important. These are currently collected in large amounts in Chile and New Zealand and should be available from culture (not from nature) to avoid destruction of habitats. It is a paradox that in New Zealand collecting of bryophytes by scientists is confined by strong regulations and high fines, while export of thousands of tons of *Sphagnum* is permitted. However, the grant applied for to grow mosses horticulturally was not awarded by the German Environmental Foundation (DBU) because of the risks involved in this project and the low proportion of alternative agriculture industry. Now attempts are being made to establish cell cultures of the bryophyte used for the extract.

Another open field of research is how bryophytes maintain the antimicrobial effects. We know (more or less) the biological active compounds and we know the effects, but we do not know how the compounds work. Preliminary studies on a molecular basis are currently being performed at the Botanical Institute in Bonn.

The antimicrobial effects of bryophytes do not only concern agriculture. Bryophytes have antimicrobial activities in general, even against human pathogenic fungi and bacteria. With regard to the total spectrum of fungi and bacteria, against which bryophyte extracts showed activity in agar plate tests, bryophytes can be called broad range antibiotics. This is known from the use of *Sphagnum* as diapers by the Natives Peoples of North America (Flowers 1957) or as surgical dressing by the Canadian Red Cross during World War I (Hotson 1918), when not only the high absorbent effect of *Sphagnum* was used but also the antimicrobial effect. Similarly, bryophytes were used in the ethnomedicine in Brazil (Pinheiro da Silva et al. 1989); China (Ding 1982; Wu 1982); England (Wren 1956); Germany (Dapper 1956); and India (Watts 1891) for their antimicrobial effects. It is also said that fungal infections of the feet (athlete's foot) can be cured by walking with bare feet through a peatbog. Based on my own experiments, I cured a fungal infection of the skin (dermatitis) with bryophyte

FIGURE 2. Liverwort and moss extracts as sold commercially.

extract. This effect was made public in a TV magazine, as well as in a book, with the result that many people used bryophyte extract for this purpose, predominantly with positive results (and sometimes with better results than prescriptions by the physicians). However, the biologically active substances (terpenoids) may have allergenic effects at least in a small number of persons and may cause dermatitis (Ando & Matsuo 1984). Therefore, the bryophyte extract may not officially be advertized for medical use, at least not in Germany. This ruling would require an indication of the active substance and tests that would show this substance is free of side effects. However, stimulated by the information on the internet (www.bryologie.uni-bonn.de), an owner of horses in Germany prepared an aquaceous paste made from *Ceratodon purpureus* and *Bryum argenteum*, which he found growing near his stable. He treated his horses for a fungus disease of the skin, since the veterinarian's treatments did not work. To his surprise, the fungus disappeared within 24 hours. The horse owner's unexpected experiences led him to apply for a patent. The story was published in a horse magazine and received much attention. From that story a company started the development of a cream with the addition of bryophyte extract. This is now sold as a cream to care for human feet—to refresh and fight odor. The true effect, cure of fungal infections, may not be mentioned for the reasons given above.

The Maoris in New Zealand treated venereal diseases by packing mashed wet bryophytes on the infected organs—they would not have continued using this if it had not worked.

A survey of the publications on the biological activity of bryophytes demonstrates that, in general, the biological activity of the total extract is higher than that of isolated compounds. Apparently so-called synergistic effects are responsible for this phenomenon that is widely found in the study of natural products.

BRYOPHYTE EXTRACT AS ANTIFEEDANT AGENT

Bryophyte extract was tested in order to obtain another patent. It is widely known, at least among bryologists, that bryophytes are not eaten by snails or slugs. Like the antimicrobial activity of bryophytes, this effect was never practically tested. The only practical experiments in this regard were made by Davidson and Longton (1987) and Davidson et al. (1990), who (unsuccessfully) tried to feed slugs with moss shoots.

At Bonn University, our first laboratory tests

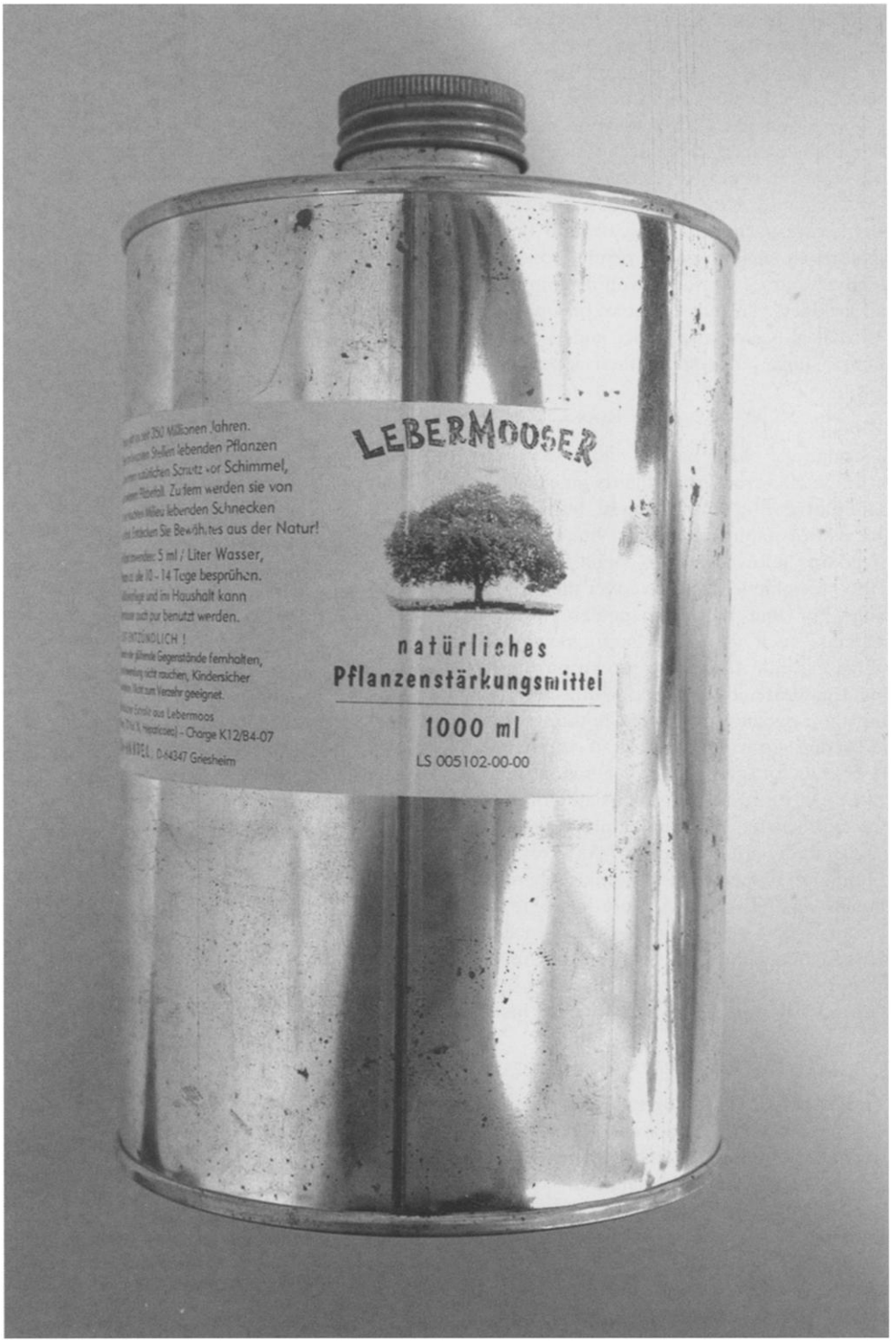

FIGURE 2. Continued.

were performed. Lettuce leaves were sprayed with different concentrations of bryophyte extracts and the same amount of a desolvent agent. These leaves were then offered to slugs as food. The result was that the leaves sprayed with bryophyte extract remained untouched at certain concentrations, whereas the leaves of the control were eaten to the midrib over night (Frahm & Kirchhoff 2002). Similar tests in the field were performed by a Federal Institute of Agriculture in Mainz and the result showed that the bryophyte extract works as well as commercial anti-snail products. The advantage of bryophyte extract is that it is a natural product and it does not kill snails or slugs, but it spoils their appetite.

Mosses as Cover for Roofs

Living naturally with natural cloth, food, and also housing is a current trend that is an expression of an alternative life style. Natural buildings include the use of natural materials, but natural aspects of houses allows them to blend into nature. One method to achieve this is to cover the roof with vegetation. For that purpose, species from dry, rocky habitats such as *Sedum* spp., *Festuca* and similar grasses, and *Allium* are grown on the roof providing a natural and very colourful aspect. Also extending the vegetation over the buildings filters dust and produces oxygen. A German company has developed mats of pre-grown vegetation that is simply attached on roofs e.g., thousands of square meters of roofing of a car manufacturer's factory in Michigan. But why not use mosses? As a test, bryophytes were grown on special loop-mats where they grow interwoven. This allows them to be used on inclined roofs. After many negative experiences using the wrong bryophyte species and sowing the mosses incorrectly, the first several thousand square meters are now in preparation (front cover inset).

Conclusions

With both the use of bryophyte extract against slugs and fungi, nature's tricks developed for protection in mosses against microorganisms and herbivores, were made usable for mankind. These special extracts are not protected by any patent except for the treatment of fungal diseases of horses, so they can be used or developed by anyone. The only knowledge required is to know the species that has the highest biological activity and how to make the extraction. The author can offer help to promote such applications.

As shown by the example of mosses on roofs, bryophytes may also play a greater role in applied botany. Although bryophytes are used for gardening, they do not seem to be used on roofs yet—and there are many more possible applications. Stone walls overgrown with mosses give a nice aspect, particularly to a garden. Why wait fifty years until bryophyte cushions have been developed when they can be grown now? Why should only vascular plants be grown and sold in nurseries while bryophytes are not? It will help when bryophytes, and also their properties, are more recognized and understood by the public.

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