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Review Article

Plant Molluscicides

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Introduction

National and international institutions are both currently giving increasing attention to the study of plant molluscicides in the hope that they may prove cheaper and more readily available than synthetic chemicals. Many developing countries are reluctant to embark on chemical snail control programmes, using costly synthetic compounds bought from industrialized nations with scarce hard currency [28, 88]. Recent rigorous legislation governing pesticide development und use, has tended to discourage the chemical industry from carrying out research even on promising synthetic compounds [137]; not surprisingly, very few candidate molluscicides are presently available [80]. Whereas synthetic chemicals biodegrade slowly, and preliminary evidence suggests that some populations of snail hosts may have developed resistance to them [7, 80], plant extracts are quite rapidly reduced to simpler substances [57, 88, 89]. Some recent studies of plant molluscicides give preliminary indications that they may be applied effectively in different habitats using techniques available in, and appropriate to, developing countries. Moreover, the use of indigenous, rather than imported, materials is desirable, especially as strategies for schistosomiasis control programmes should be based on long-term operations. Such strategies should ideally employ a multiplicity of methods (including population chemotherapy, focal and seasonal snail host control, environmental and sanitation improvement and health education), rather than a single approach.

Research on plant molluscicides has become multidisciplinary and, as a consequence, the findings have been reported in a wide variety of journals. No comprehensive review on plant molluscicides having yet been published, the purpose of this paper is to assemble pertinent information and provide general guidelines and recommendations relevant to further research on plant molluscicides and their role in control programmes.

Review

Interest in plant molluscicides dates from the 1930's when Archibald [12] and Wagner [131] advocated planting the desert palm, *Balanites aegyptiaca* and *B. maughamii*, along the water courses of the Sudan and southern Africa, respectively. The laboratory and field trials of these scientists indicated that the fruit which fell into the water inhibited the increase of snail population density. These encouraging findings prompted the introduction of *B. aegyptiaca* to Puerto Rico, where it was planted around a *Biomphalaria glabrata* infested pool with apparently beneficial results [99]. Mozley [86, 87] considered this and two other saponin-containing plants, *Sapindus saponaria*, the berries of which were widely used in Africa and South America as a fish poison and soap, and *Swartzia madagascariensis*, a traditional African medicine and fish poison [131], to be among the most promising of vegetable molluscicides. Using the berries of *S. saponaria*, he controlled a population of *Bulinus (Physopsis) africana* in a pond in Zanzibar. In South America, preliminary studies by Luttermoser [73] in Venezuela, and by Pinto and Almeida [98] in Brazil, showed that the berries of *S. saponaria* were lethal to numerous microscopic organisms, as well as to the host snails of *Schistosoma* and *Fasciola* [129]. Synergistic effects were found between extracts of *S. saponaria* and sodium pentachlorophenate [17, 85]. None of these plants, nor several additional Old World fish poisons [87, 110, 126], was further exploited for the control of snails. Not until the mid-1960's was the first plant *(Phytolacca dodecandra)* used for control of schistosomiasis in an endemic focus, in Ethiopia [62].

Stimulated by these early studies, the search for plants with molluscicidal potential was intensified as exemplified by extensive screening and general improvement of methods and techniques (Table II). Amorin and Pessoa [10] randomly screened fresh material of nine plants indigenous to Alagoas State, Brazil. Three of the plants, *Paullinia pinnata, Stenolobium velutinum* and *Piptadenia macrocarpa*, were found to be only mildly molluscicidal at 1000 ppm, apparently due to the green state of the plants. Silva et al. [117] screened another 30 species indigenous to Brazil, of which four were toxic to *Biomphalaria straminea*, but only one, *Agonandra brasiliensis*, was molluscicidal at 100 ppm. Possible confinement of the active ingredient in the bark, which regenerates slowly, of *A. brasiliensis* and *Brysonima sericea* (other parts of the plants were not tested) probably precludes their practical use for snail control. The bark of *Ziziphus undulata* was found to have no effect on the snails, but Barbosa and Mello [18] reported 30 percent mortality in *Biomphalaria glabrata* exposed to a 10 ppm water extract of *Z. joazeiro*. In northeast Brazil several of about one hundred plants studies, including *Pithecellobium multiflorum* and *Piper tuberculatum*, showed promising molluscicidal activity [105]. However, fish succumbed at concentrations lower than those which killed snails [106], and the resistance of the plants to physiochemical stress (sunlight, temperature, silt and pH) remains to be studied before their suitability can be more fully assessed.

Medina and Woodbury [82] tested 198 plants indigenous to Puerto Rico and two to the Dominican Republic. The plants selected for screening were from genera known to have molluscicidal activity, plants with medicinal or toxic effects in man or domestic animals, as well as some species randomly selected from areas infested with lymnaeid snails. All parts of the plant were tested. Thirty species were found to be lethal to *Lymnaea cubensis* and *L. columnella* in water extract of 1000 ppm. For further screening these plant products were oven-dried and tested in water extracts at 25, 100, 200 and 1000 ppm. Although *Hedychium coronarium* yielded the most potent extract, *Solanum nodiflorum* was selected for further study, due to the uniform distribution of the molluscicidal principle in all parts of the plant [82, 83]. All other species exhibited great variations in potency, but the highest toxicity levels were most often found in the flowers and leaves. Several species of *Solanum* are being cultivated for solasodine, a sapogenin used in the production of pharmaceutical steroids, and attempts are being made to cultivate *S. mammosum* in Puerto Rico [128]. Solasodine and possible solamargine, another glycoalkaloid in the fruits of *S. mammosum*, were significantly more toxic than the crude aqueous and methanolic extracts [8]. Although the small number of species tested by Medina and Woodbury [82] do not permit detailed comparisons between plant families, it was noted that the greatest proportion of molluscicidal plants found was in the Solanaceae (8 of 14 plants tested), Phytolaccaceae (both species), Fabaceae (3 of 15), Rubiaceae (2 of 12) and Euphorbiaceae (2 of 13). All 9 species of the family Compositae and the 6 grasses were found to be nontoxic to snails. These findings reveal certain similarities and contrasts to other studies. Thus, although *Jatropha curcas* had no effect on *Lymnaea* sp. in Puerto Rico [82], its roots proved highly molluscicidal against *Oncomelania quadrasi* in the Philippines [142], and its seeds moderately so against *Bulinus truncatus* in Sudan [32]. Whereas *Randia aculeata* and *Canna* sp. were well tolerated by *Lymnaea* sp., [82], the fruit and root of *R. nilotica* tested by El-Kheir and El-Tohami [32], and *Canna indica* tested by Mahran et al. [75], and *Adewunmi* and *Sofowora* [5], were molluscicidal. *Paullinia pinnata*, well tolerated by lymnaeid snails [82], caused 100 percent mortality in *B. glabrata* as a 1000 ppm water extract [10], but species of *Ipomoea, Urera* and *Serjania* were nontoxic in both studies. Similarly, *Borreria vercillata* and the two species of *Annona* tested by Medina and Woodbury [82] and Silva et al. [117], showed no molluscicidal activity at 1000 ppm. The toxicity of two species of *Phytolacca* against *Lymnaea* spp. corroborates the findings of several investigators [56].

Twenty-three of the 181 methanolic extracts (12.7 percent), representing 106 plant species used in Nigerian herbal medicine, gave 100 percent kill against *Bulinus (P.) globosus* [5]. They include the root of *Rauvolfia caffra*, the stem and root of *Bombax costatum*, the fruit of *Dialium guineense*, the root and stem of *Combretum* spp., and the root of *Terminalia mollis*, the root of *Cyrptogonone argentea*, the stem of *Acioa emenii* and *A. ruatisii*, the leaves of *Morinda lucida* and *Rothmania whitefieldii*, and the leaves of *Xiris anceps*.

The suitability of plants having molluscicidal activity only in the roots and stems depends primarily on their rate of growth, potency and amount of labour involved in digging up the roots. Plants endowed with regenerative fruiting parts and seeds, being more easily harvested, transported and processed, should normally be given preference. Nevertheless, vegetatively grown tubers may be used advantageously in some locales, since they may not require milling or storage and can remain in the ground until used. Their weight and bulk, however, pose problems during digging and transportation, as noted by Teesdale [126], who field-tested the root of *Neorautanenia pseudopachyrhizus* in Kenya.

The most extensive plant screening programme has been carried out in China, where nearly 600 indigenous herbs were tested for snail toxicity. Fewer than 20 were mildly toxic in concentrations of 10.000 ppm and lower; no plant was considered to be cost-effective for large-scale use [74].

Some of the reported variations in toxicity between plants studied by different investigators are probably due to differences in collection methods, plant varieties and ecotypes, extraction solvents and snail species and subspecies used. Unfortunately, exact locations of plant collection sites and maturation stage are seldom indicated in reports, and duplicate specimens are not always secured for deposition in herbaria for reference purposes. Concentration of active substances varies not only among different plant parts, but also among specimens from the same species growing in the same areas [82]. Although many plant materials are more efficiently extracted when ripe and in powder form, higher potencies were reported for the green and semi-ripe, than for the fully ripe berries of *Phytolacca dodecandra* [54, 71]; moreover, female plants of this dicot are more toxic than male plants [54]. Identification of plants is not always complete or correct, due to failure to obtain flowering and fruiting parts and to lack of competent plant taxonomists. Several investigators [32, 132], while searching for the most potent molluscicides, failed to report findings on plants possessing no molluscicidal attributes but which might be useful for comparative studies, or in reducing duplication of work in an attempt to lower research costs [36]. The discovery that the bark of dogwood (*Cornus florida*) is toxic to snails [45] is of little relevance for control of snail-transmitted diseases, since this plant occurs only in the higher latitudes of North America and Eurasia [100].

Another problem in developing molluscicidal plants is the lack of information on their toxicity to man, domestic animals and non-target aquatic fauna and flora, although the relatively few plant species screened for molluscicidal activity have already been studied chemically and pharmacologically [14, 44, 130, 133]. *Croton tiglium*, studied in China and in the Philippines, has a potency against *O. quadrasi* comparable to that of the synthetic molluscicide Bayluscide®, but is hazardous for snail control due to the carcinogenic effect of croton oil [24, 142]; it shows antileukemic activity at low dosages [25]. The seeds of the closely related *C. macrostachys*, known by the same vernacular name as *C. tiglium* in Sudan, and considered promising for snail control [9, 28], also need to be studied for possible carcinogenicity. Another plant indigenous to the Philippines, *Entada phaseoloides*, was lethal against *O. quadrasi* at low concentrations and was stable under various physiochemical stresses, but killed fish below its molluscicidal level. The relatively high doses required to obtain a satisfactory molluscicidal effect in a field trial, as well as the use of its bark, mitigate against its application in control programmes [140].

Other plants, whose toxicity should be studied before being subjected to intensive molluscicidal tests, include species of the genus *Derris*, some of which have been associated with human fatalities, and *Jatropha* spp. [86, 124] and *Securidaca longepedunculata* which has been used as a homicidal plant and fish poison in Angola [15]. Research on *Euphorbia candelabrum* was discontinued in Ethiopia due to its toxicity in man, in spite of the fact that its latex was molluscicidal at 20 ppm. The seeds of the common castor plant, *(Ricinus communis)*, were nonmolluscicidal [22, 82]. The three furcoumarins in *Ammi majus*, including bergapten, claimed to be as active as sodium pentachlorophenate (NaPCP) in Egypt, and safe for handling [1], are all strong dermal photosensitizers [111].

The discovery of molluscicidal and snail-repellent hydrophytes, and of plant wastes that are toxic to snails, has further increased the prospects of developing plant molluscicides, using simple technology. Aquatic plants provide support, food and shelter for the survival and maintenance of snail intermediate hosts. Bousfield [23] found strong associations between rheotaxis of *B. glabrata* snails and various plant species. While extracts from *Potamogeton crispus* and lettuce *(Lactuca sativa)*, among other plants, attracted the snails, those of *Apium nodiflorum* and water cress *(Rorippa nasturtium aquaticum)* repelled them.

These differences were attributed to antagonistic substances in plants which may interfere with the chemical sensory mechanisms of snails and inhibit or reduce positive rheotaxis. This hypothesis is supported by the results of several other studies. Mahran and coworkers [75] noticed a general absence both of snails and dead specimens in stretches of water courses inhabited by *Canna indica*, which is molluscicidal. In Kenya Dossaji et al. [30] noted high mortality of snails in a reservoir where *Polygonum senegalense* forma *senegalense* was abundant. An extract of fresh leaves was found to be slightly molluscicidal; the chemical structure of the active principle, phenolic glycoside, was studied by Maradufu and Ouma [78]. The freshwater alga *Chara vulgaris* was associated with high snail mortality in aquaria [103]. However, the algal complex *Mycrosystis farlowiana/Pseudanabaena franqueti* was molluscicidal against *Lymnaea* sp. only at high concentrations [42]. Warren and Peters [132] reported that *Schistosoma mansoni* cercariae penetrated the integument of the string bean *(Phaseolus vulgaris)* but not of 81 aquatic plants, one of which, *Hedychium coronarium*, released a cercariacide when cut, suggesting that this and other plants studied (none was listed in their report) may be molluscicidal as well. During another screening programme 20 of 100 essential oils, containing diterpenes, sesquiterpenes and related substances, inhibited penetration of *S. mansoni* cercariae through the skin of mice, seven of them killing all cercariae [36].

Some food and fibre plants, widely cultivated and processed in the tropics and subtropics, yield waste

products which are toxic to snails. The waste from sisal *(Agave sisalana)*, discarded by some factories into rivers in Tanzania, kept large stretches of water free from schistosome-transmitting snails, apparently as a result of oxygen depletion [89]. Such pollution, however, can hardly be advocated as a method of snail control. The presence of saponins in sisal waste, which, according to this author, appear to be nontoxic to man, seems to warrant a search for molluscicidal activity in other plants of the Agave family. The presence of hecogenin in the juice of sisal has led to increased production of this plant in Tanzania, Kenya and Brazil [19]. *Yucca schidigera* is molluscicidal [104], but steroidal hecogenins in some Agave species may have a fertility effect on snails [81, 96], and wild yucca and agave may grow too slowly for large-scale use [128]. Molasses, a byproduct of sugar refining, was found to act both as a molluscicide and a fertilizer when discharged into the irrigation system of a sugar estate in Tanzania [109]. In Ethiopia, however, concentrations of 5.000 ppm did not affect *Biomphalaria* snails in the laboratory [31]. The shell of the cashew nut *(Anacardium occidentale)*, in an hexanic extract, killed young and adult *B. glabrata* snails and their eggs at very low concentrations [95]. The active principle is four compounds of anarcadic acid [122], the chemical structure of which has been studied by Lloyd et al. [67]. The waste of other plants, commonly discarded and found to kill snails, such as the leaves of chili pepper *(Capsicum frutescens)* and tomatoes [82] may prove to be cheap and readily available sources of molluscicides.

In many schistosomiasis endemic areas, the leaves, fruits and nuts of trees and bushes, which have molluscicidal properties, were widely gathered for various purposes by rural populations. For example, the leaves of the leguminous *Dichrostachys glomerata*, the fruits of which are eaten in tropical Africa, the leaves of *Lophira alata*, sought for the oil in its nuts, and the leaves of *Ximenia americana*, a bush used for its fruit throughout tropical Africa [47], are all molluscicidal [5]. Leguminous trees, including species of *Acacia, Pithecellobium, Parkia* and *Prosopis* are ideal food plants in semiarid climates, due to their high quality seed protein, drought resistance and minimum cultivation requirements [38] and also exhibit properties toxic to snails. While the complementary use of such xerophytic trees for food and molluscicides should be given greater attention, trees producing edible parts that have also snail-killing properties, including the fruits of *Balanites aegyptiaca* and *Tetrapleura tetraptera*, are less likely to be cultivated primarily for snail control in areas where they are a food source or considered sacred. Similarly, the molluscicidal properties of tobacco [102] have little practical application due to high production costs. The study of cercaricidal essential oils in some food plants, including the leaves of green pepper *(Capsicum annuum)* [39], and of cercaricidal and molluscicidal compounds in garden flowers [43, 48] has received little attention and may merit further study if prolonged effects can be achieved.

Of the few plants that have been tested in field trials, *Phytolacca dodecandra*, known as *endod* in Ethiopia, where its berries are used as the major traditional laundry soap and also as a medicine [49, 53] has been studied in depth and can provide a favourable model [59, 137]. Following encouraging field trials in a small lake and in canals of a sugar cane plantation [54] crude ground endod berries in water extract were periodically applied to the streams in Adwa town, northern Ethiopia, during a five-year schistosomiasis control programme. The decrease in the prevalence of *S. mansoni* infection in the 1–5 year age group was attributed to successful snail control [62], but other factors may have been involved. Earlier laboratory studies had shown that the berries, the most potent part of the plant, were highly toxic against all major snail hosts of *Schistosoma* and *Fasciola* [16, 57, 58, 139]. The active principle of *endod* is several derivatives of oleanolic acid of a triterpenoid saponin [94]. Its potency is stable within a wide range of pH, temperatures, ultraviolet radiation and following storage for a period of more than five years, but like most other plant and synthetic molluscicides, it is absorbed in suspended matter [54, 57, 58]. Development of a colorimetric method for quantitative assay of the active substance in treated waterbodies may facilitate application of proper doses in different habitats [63, 66]. Like many other molluscicides, *endod* is toxic to tadpoles, schistosome cercariae and miracidia, fish and leeches, but in recent field trials, tadpoles, frogs and aquatic insects were apparently unaffected [72]. Endod is not lethal to the egg masses of snail hosts at molluscicidal concentrations, which is a marked disadvantage, as to provide effective results "the frequency of snail operations must be doubled" [80], this in turn increasing fish kill and probably the magnitude of other ecological disturbances. Its mammalian toxicity appears to be comparable to many other saponin plants [41, 54, 58, 77]. No permanent plant toxicity was noted during continuous application of high concentrations to local plants grown experimentally [143], and no mutagenicity was detected during a preliminary restricted study using a bacterial plate test devided by Ames [55]. To date the chronic toxicity of *endod* has not been adequately investigated [80].

The water/fermentation extraction process recently developed at the Institute of Phathobiology in Addis Ababa [64] eliminates the need for elaborate extraction and drying apparatus earlier used in the more expensive butanol extraction process, at the same time yielding a molluscicide with comparable potency (4 ppm) [64]. The sevenfold increase in potency of the water/fermentation extract, in comparison with

the crude berries, may, once large-scale cultivation of *endod* takes place, reduce its cost for snail control to a level where it could become competitive with Bayluscide®, at present the only synthetic molluscicide in use [80]. During the schistosomiasis control project in Adwa, crude *endod* berries were bought in local markets, no comparative cost estimates were made, but the cost of the programme was US $ 0.03 per head of the population [62]. The cultivation of selected strains with berries that are molluscicidal at 5 ppm may permit their application without extraction in the future. Lugt [68] estimated that 1.0–1.5 ha of *P. dodecandra* selected types are sufficient to treat 10.000 ha of irrigated sugar cane. In recent field trials, involving the use of high potency strains, only 2.2–3.5 kg crude *endod* powder were required to treat effectively 300 metre stretches of two small Ethiopian streams per application [72].

The use of the water/fermentation extraction process for other purpose is being investigated, and studies are underway to develop methods to extract secondary constituents of the *endod* berries for use in various products. These may include antifertility and contraceptive agents [121], antiviral, antibacterial, antifungal and antihelminthic compounds [60, 138], unsecticides and larvicides against houseflies and species of *Simulium*, the vector of river blindness, and *Anopheles* mosquitoes [13, 61, 119], industrial detergents, drying regulators in cement and anticholesterol medicines [76, 92]. Such additional uses may solve the problem of the low and seasonal demand for *endod* as a molluscicide.

Apart from the unresolved reservations concerning the chronic toxicity of *endod* to non-target organisms, including man, a major constraint in the wide use of the berries of this plant in snail control programmes has been failure to grow *P. dodecandra* on a large scale until the late 1970's, due mainly to the low demand for molluscicides in Ethiopia, as well as insufficient knowledge of its growth requirements in different soils and climates, and its susceptibility to pests. Several species of insects attack the leaves and shoots, and nematodes the roots [72, 125]. After obtaining promising results, Lugt [72] recommended the cultivation of insect-resistant strains of *endod*. In Ethiopia the *endod* bush grows naturally only in the cool, humid highlands above ca. 1500 m, and has only recently been planted for field trials in the hot, arid lowlands, where schistosomiasis is most prevalent [50]. Whereas technical problems of *endod* cultivation may be largely solved through selection and breeding of hardy and disease-resistand varieties, and by proper crop management [72, 84], the question of low demand for molluscicides in Ethiopia is more serious. Regular application of molluscicides in Ethiopia is presently confined to the Wonji-Shoa sugar cane irrigation scheme, the only farm where *endod* is grown on a large scale. In 1970, 130 l of Frescon® and 250 kg of Bayluscide® were applied experimentally over part of that farm at a cost of nearly US $ 4000 [31]. Failure to treat other irrigation schemes reflects prevailing health policy priorities and the poor economy of Ethiopia. These constraints may well curtail further research on several other potential plant molluscicides in that country, including the leaves of *Sesbania sesban* [127], and the leaves and stems of *Withania somnifera*, a household medicine [49] which also contains an antitumor and antiarthritic steroid lactone [40]. The occurrence of *P. dodecandra* throughout Africa [133], and of several other species of *Phytolacca* in Central and South America and Asia [29, 52, 95], may stimulate further studies on the byproducts of species and strains of this genus.

The annual herb *Ambrosia maritima* is known under the vernacular name *damsissa* in Egypt, where it occurs throughout the Nile valley and delta [123]. This plant has been studied at Alexandria University for more than 25 years for use in community-level snail control programmes. Its flowering parts and leaves are moderately molluscicidal, and alcoholic extracts do not increase potency [113, 114]. The extracted active substances damsin, ambrosin and tribromo-damsin [3] proved to be highly molluscicidal. *Damsissa* is non-toxic to cattle and sheep, which commonly graze on this plant, to fish and apparently to man, who traditionally used concoctions and infusions from the flowering parts as an antispasmodic in colics, as a diuretic [113], and as a remedy for haematuria in *Schistosoma haematobium* infection [51]. In field trials, significant reductions in snail populations were achieved when whole *damsissa* plants were placed into canals [115], and also by growing the plant on canal banks where the fluctuating water leached out the active principle from the flowering parts and leaves [34]. This method of natural control resembles that earlier advocated by Archibald [12], Wagner [131] and Anantaraman [11], who proposed that fruit and leaves with molluscicidal properties, falling from trees planted along water courses, might control snail host populations. In spite of this desirable feature of *damsissa*, and the fact that its flowering period coincides with the seasonal peak of schistosomiasis transmission in Egypt, there are serious constraints, mostly associated with ecological pressures, which curtail its usefulness. In addition to growing poorly along drainage canals due ot its poor adaption to saline soils [34], it is damaged by grazing livestock and its habitat has been drastically reduced since the end of the annual Nile flood [33, 120]. Moreover, this small, prostrate plant is commonly destroyed during mandatory canal cleaning operations. *Damsissa* has not been grown in sufficient quantities for self-reliant community snail control programmes and, as already mentioned, the great land pressure in Egypt would tend to prohibit its cultivation in plots. The relatively low molluscicidal activity of the water extracts, the high

cost of extracting the active principle, their instability under simulated field conditions [116] and, not least, the widespread occurrence of host snails in the extensive irrigation networks of Egypt further diminish its usefulness in snail control. The recent discovery of saponin plants in Egypt [2, 111], the use of natural products with molluscicidal properties by Egypt's pharmaceutical industry [136], and the presence of several well stocked herbaria in Cairo may encourage the search for other, more suitable plants.

The seeds of *Croton macrostachys*, used as a purgative and antihelminthic in Sudan, where it is known as *habat-el-mollok*, were recently screened for molluscicidal activity by DAFFALA and AMIN [28]. The results of the comparative laboratory tests show that *habat-el-mollok* seeds are more toxic than crude *endod* berries. Molluscicidal potency of the water extract was not affected by pH 4–10 or by storage for six days; it increased with temperature, but rapidly declined with increasing turbidity. Several species of fish were killed at molluscicidal concentrations, but its mammalian toxicity was acceptable and no phytotoxicity was detected. Field application of the water extract at 2 ppm controlled snails in a stagnant canal for three months. Aquatic plants and most fauna were not affected. The use of only six kilos of the seed for treatment of 3000 m^3 of canal water [28] compares favorably with *endod*, but in a laboratory experiment by LUGT [72] in which *C. macrostachys* seeds from Khartoum markets were used, no molluscicidal activity was observed. Preliminary studies of its chemistry show that saponins constitute the active substance, but the presence of alkaloids [28] requires that the seeds be further studied for non-target toxicity. This is all the more necessary as Sudanese people consider *habat-el-mollok* to be highly toxic to humans, and because the related *C. tiglium*, also known under this vernacular name in Sudan [28], is carcinogenic.

The low molluscicidal potency of the fruit of *Sapindus saponaria*, which required the application of 1 kg of fruit per m^3 of water in a pond in Zanzibar [88], tends to limit its use to small waterbodies, many of which may be important schistosomiasis transmission sites in certain areas of East Africa [79]. Scarcity of this plant in endemic areas will require that it be planted near snail habitats, if only to minimize transport costs.

PEIRERA et al. [97] studied the stem of *Euphorbia cotonifolia*, an ornamental plant in Brazil. The fractioned hexanic extract was highly toxic to *Biomphalaria glabrata* and its eggs in the field, but killed fish at lower dosage levels.

The tuberous root of *Neorautanenia pseudopachyrhizus*, a common herbaceous plant on the East African coast, was found to cause more than 50 percent mortality in *Bulinus (P.) globosus* when applied in a pool in Kenya at a concentration of about 500 ppm. At that concentration it was not piscicidal and was well tolerated by monkeys [126]. This author suggested that the plant be cultivated near snail habitats to minimize transport of the heavy and bulky roots, the major disadvantage associated with its use.

In Nigeria encouraging results were obtained with the aqueous and methanolic extracts of *Tetrapleura tetraptera*. In a schistosomiasis control project at Fasina and Abun-Abon the methanolic extract was stable under field conditions and had little mammalian toxicity and no phytotoxicity [6]. Another Nigerian medicinal plant of the Mimosa family, *Calliandra portoricensis*, was highly piscicidal [4].

The seeds of the Brazilian leguminous tree, *Pithecellobium multiflorum*, are highly active against *Biomphalaria* adults and eggs [106, 107]; they may be another promising plant molluscicide and should be field tested.

Summary and Conclusions

Research on plant molluscicides is gaining support at a time of slow growth in synthetic molluscicides. During the past 50 years, more than 1000 plant species have been screened, most of them superficially, for molluscicidal activity. The richness of the flora in most areas where snail-transmitted diseases are endemic, suggests that many plants with molluscicidal properties remain to be discovered. The recently developed computerized information system NAPRALERT (Natural Products Alert), designed to bring together the world literature with regard to plant, animal, microbial and marine organisms, represents a valuable aid in the search for molluscicidal plants. This system, supported by the World Health Organization, provides ethnomedical information, biological data for extracts and the isolation or identification of secondary constituents with their appropriate literature citations [37]. Botanical descriptions in herbals and herbaria and anthropological accounts of plant use [112] as well as herbalists [5] and market surveys [32, 49], can provide additional leads.

The desirable characteristics of plant molluscicides are listed in Table I. Several promising plants have already been identified. *Endod (Phytolacca dodecandra)*, in particular, compares fairly well with the major synthetic molluscicides in terms of potency, and has the advantage of yielding other products of pharmaceutical and industrial interest. However, its chronic toxicity is unknown and its use under most field conditions is, therefore, precluded.

The use of plant molluscicides may not only eliminate the expense of importing costly synthetic molluscicides, but could also stimulate growth of small-scale industries in developing countries. More emphasis, however, must be placed even from the beginning on agronomic and organizational aspects, including community participation, if plant molluscicides are

Table I
Desirable characteristics of molluscicidal plants

Toxicity	High toxicity against target organisms; low or no toxicity against non-target organisms at molluscicidal concentrations.
Supply	Readily available locally
Yield	High yield of molluscicidal material per plant and per unit area of cultivated land.
Type of plant	Perennial rather than annual; reproduce by seeds rather than by tubers; drought resistant for use in arid areas; semiaquatic or aquatic for use directly in snail habitats; high propagation and rapid growth rates with minimum capital and labour input; high adaptability to differing local environmental conditions; high resistance to pests, weeds etc.
Plant parts	Localization of high potency levels in regenerating parts (berries, fruits, flowers, nuts, deciduous leaves) or vegetatively planted tubers.
Storage	Molluscicidal material of seasonally producing plants should not lose potency during storage of at least one year.
Extraction	Active principle should be extractable by simple apparatus and commonly available solvents, preferably water
Physio-chemical stability	Retention of molluscicidal potency under physiochemical influences (pH, sunlight, temperatures, silt, organic matter, water pollution) normally found in the endemic area during the annual cycle.
Knowledge of plants in endemic area	A good knowledge of growing habits and requirements, toxicity and any medicinal properties of plants by local people, is an asset.
Cultural acceptability	Absence of spiritual and ceremonial uses of plants and aversions based on folklore and magic, which might interfere with their use for snail control, is desirable.
Additional uses	Suitability of the same plant parts for other public health, local, domestic or industrial uses.

to be applied successfully in long-term and self-sustained snail control programmes.

Major constraints presently limiting the use of plant molluscicides are lack of adequate information on their cost-effectiveness and chronic toxicity, and difficulties of developing viable snail control programmes in rural areas using local resources. Snail control has traditionally been carried out, using imported synthetic chemicals, with minimum or no involvement of local people, by health officials and technicians of central governments and international organizations. The very nature of natural products, processed and applied in the country of origin, makes it imperative that governments, research institutes and rural communities undertake collaborative programmes designed to screen, cultivate, apply and monitor effects of carefully selected plant products. Costs will be highest during the initial development phases, but use of local labour for cultivating, harvesting, processing and applying plant molluscicides, reduced transportation costs and new methods of screening and extracting active compounds, can make them more cost-effective. The extensive knowledge most rural people have of local plants with toxic and medicinal properties, together with new information on chemotaxonomy, will permit focused screening of those families and genera that are most likely to contain species suitable for effective snail control.

Although several research programmes have successfully tested plant materials, using techniques commonly used in phytochemical and pharmacological studies, more effective exchange of information is needed do develop specific research methodologies and snail control strategies. It is clear that more integrated laboratory and field trials, including acute and chronic toxicity studies, the evaluation of plants for cultivation under diverse local conditions, and their suitability for exploitation by intermediate technologies, are urgently needed.

Perhaps there is need to emphasize that the methods used for biological and chemical screening of plants have lacked standardization. Many have been inadequate, contributing to unexplained variations in results reported by different scientists in respect to the same plant species, and consequently impeding efforts to assess their true impact on ecosystems. Screening and evaluation methods developed by the World Health Organization [134, 135] should be used.

In future, more attention must be paid to the development of simple, cheap and efficient extraction and application techniques amenable for use in rural communities. With community development and appropriate technology becoming an important element in revised national socio-economic planning, many endemic countries can now support, with justification, the development and evaluation of plant molluscicides as a new tool in the implementation of internally directed and properly sustained health improvement campaigns.

Table II

Summary of toxicity studies

Plant species, by family	Parts tested (extract*)	Concentration tested (time of exposure)	Mortality (%)	Target species	Other effects	References
AGAVACEAE						
Agave sisalana	Leaf (W)	5000 ppm (24 hr)	90	*B.(P.) globosus*	Destroys most aquatic fauna and flora	91
ALPINACEAE						
Hedychium coronarium	Seeds (W)	25 ppm (24 hr)	100	*Lymnaea cubensis L. columella*	Cercaricidal	82, 132
ANACARDIACEAE						
Anacardium occidentale	Shell (SM)	0.35 ppm (24 hr)	50	Adult *B. glabrata*	Not studied	122
Anacardium occidentale	Shell (H)	0.6 ppm (24 hr)	50	Adult *B. glabrata*	No toxicity in mice	95
Anacardium occidentale	Shell (H)	1.4 ppm (24 hr)	50	Newly hatched *B. glabrata*	Not studied	95
Anacardium occidentale	Shell (H)	18 ppm (24 hr)	50	*B. glabrata* eggs	Not studied	95
Anacardium occidentale	Shell (H)	1 ppm (1 hr)	50	*S. mansoni* cercariae	Not studied	95
Anacardium occidentale	Shell (H)	3 ppm (24 hr)	20	Fish *(Lebistes reticulatus)*	Not studied	95
ANNONACEAE						
Annona senegalensis	Stem (M)	100 ppm (24 hr)	85	*B. globosus*	Not studied	5
APOCYNACEAE						
Rauvolfia caffra	Root (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
ASCLEPIADACEAE						
Cryptostegia grandiflora	Stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
BOMBACEAE						
Bombax costatum	Root, stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
CAESALPINIACEAE						
Dalium guineense	Fruit (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
CANNACEAE						
Canna indica	Whole plant (W)	820 ppm (24 hr)	98	*B. alexandrina*	Not studied	75
Canna indica	Whole plant (Er)	170 ppm (24 hr)	98	*B. alexandrina*	Not studied	75
Canna indica	Root, leaves (M)	100 ppm (24 hr)	5–10	*B. (P.) globosus*	Not studied	5
CHARACACEAE						
Chara vulgaris	Whole plant (in aquaria)	Plants in aquaria	100	*B. glabrata*	Not studied	103
COMBRETACEAE						
Combretum spp.	Stem, root (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Terminalis mollis	Root (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
COMPOSITAE						
Ambrosia maritima	Flowers, leaves (W)	1000 ppm (12, 24 hr)	30, 100	*Bulinus* sp.	No effect on *Tilapia nilotica*, and *Anopheles* and *Culex* larvae	113
Ambrosia maritima	Flowers, leaves (hot A)	2000 ppm (24 hr)	0	*Biomphalaria* sp.	Not studied	113, 114
Ambrosia maritima	Flowers, leaves (W)	1000 ppm (48 hr)	100	*S. haematobium* eggs	Not studied	113, 114
Ambrosia maritima	Flowers, leaves (W)	1000 ppm (30 min)	100 (?)	*S. haematobium* miracidia and cercariae	Not studied	113, 114
Ambrosia maritima	Damsin, ambrosin and tribromo damsin (S,A,C,E)	9.7–14.5 (24 hr)	90	*B. alexandrina, B. truncatus*	Not studied	116
Ambrosia maritima	Flowers, leaves (W, field trial)	Approx. 70 ppm (?)	Reduction in snails for 7 weeks.	*B. alexandrina B. truncatus*	No fish toxicity noted	115, 34
CORNACEAE						
Cornus florida	Bark (M)	100 ppm (24 hr)	„Molluscicidal"	*B. glabrata*	Not studied	45

Table I Cont.

Plant species, by family	Parts tested (extract*)	Concentration tested (time of exposure)	Mortality (%)	Target species	Other effects	References
CUCURBITACEAE						
Luffa operculata	Fruit (W)	1000 ppm (24 hr)	60	*B. stramina*	Not studied	117
EUPHORBIACEAE						
Bridelia adroviridis	Stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Croton macrostachys	Seeds (W)	1.0 ppm (24 hr)	90	*B. truncatus*, *Lymnaea* sp.	Not studied	28
Croton macrostachys	Seeds (W)	20 ppm (24 hr)	90	*B. pfeifferi*	Not studied	28
Croton macrostachys	Seeds (W)	50 ppm (24 hr)	90	*B. glabrata*	Not studied	28
Croton macrostachys	Seeds (W)	20 ppm (?)	100 (?)	Eggs of *B. pfeifferi* (late stage)	Not studied	28
Croton macrostachys	Seeds (W)	1000 ppm (8 hr)	No effect	Cercariae and miracidia of *S. mansoni* and *S. haematobium*	Not studied	28
Croton macrostachys	Seeds (W)	45 ppm (24 hr)	50	*Tilapia nilotica*	Not studied	28
Croton macrostachys	Seeds (W)	20 ppm (24 hr)	50	*Gambusia affinis*	Not studied	28
Croton macrostachys	Seeds (W)	1 ppm (24 hr)	50	Rat *(Arvicanthis niloticus)*	Not studied	28
Croton macrostachys	Seeds (W, field trial)	2 ppm (24 hr)	Snails controlled for 3 months	*B. truncatus*	Several species fish killed; no phytotoxicity noted	28 28
Croton tiglium	Seeds (W)	0.7 ppm (48 hr)	50	*O. quadrasi*	Skin irritant in paste form	141
Croton tiglium	Seeds (W)	0.007 ppm (48 hr)	50	Fish *(Oryzias latipes)*		141
Croton tiglium	Seeds (Er)	0.09–1.0 (48 hr)	50	*O. quadrasi*	Not studied	141
Croton tiglium	Seeds (W, field trial)	4 g/m^2 (?)	90 +	*O. quadrasi*	Not studied	141
Croton tiglium	Seeds (W)	1.6 g/kg of body weight (?)	50	Mice	Not studied	141
Cyrptogonone argentea	Root (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Euphorbia cotonifolia	Leaves (H)	1.2–3.4 ppm (24 hr)	90	Adult *B. glabrata*	Not studied	97
Euphorbia cotonifolia	Leaves (H)	4.8–8.0 ppm (24 hr)	90	Newly hatched *B. glabrata*	Not studied	97
Euphorbia cotonifolia	Leaves (H)	13–48 ppm (24 hr)	90	*B. glabrata* eggs	Not studied	97
Euphorbia cotonifolia	Leaves (H)	6 g/kg of body weight	No effects	Mice	Not studied	97
Euphorbia cotonifolia	Leaves (H)	2.5 ppm (24 hr)	100	Fish (*Lebistes reticulatus*)	Not studied	97
Euphorbia cotonifolia	Leaves (H)	9.6 ppm (24 hr)	100	*S. mansoni* cercariae	Not studied	97
Euphorbia lactea	? (E)	2.4 ppm (?)	50	*B. alexandrina*	Not studied	2
Euphorbia lactea	? (B)	9.8 ppm (?)	50	*B. alexandrina*	Not studied	2
Euphorbia lactea	? (P)	5 ppm (?)	50	*B. alexandrina*	Not studied	2
Euphorbia lactea	? (Er)	4 ppm (?)	50	*B. glabrata*	Not studied	2
Euphorbia lactea	? (Be)	4.8 ppm (?)	50	*B. alexandrina*	Not studied	2
Jatropha curcas	All parts (W)	1000 ppm (24 hr)	No effects	*Lymnaea cubensis*	Not studied	82
Jatropha curcas	Seeds (W)	27.5–48.5 (48 hr)	90	*O. quadrasi*	Not studied	142
Jatropha curcas	Seeds (M)	6.7 ppm (48 hr)	50	*O. quadrasi*	Not studied	142
Jatropha curcas	Seeds (B)	45 ppm (48 hr)	50	*O. quadrasi*	Not studied	142
Jatropha curcas	Seeds (C)	65 ppm (48 hr)	50	*O. quadrasi*	Not studied	142
Jatropha curcas	Seeds (Be)	40 ppm (48 hr)	50	*O. quadrasi*	Not studied	142
Jatropha curcas	Seeds (W)	10 g/kg of body weight (one dose)	No effects	Mice	Not studied	142
Jatropha curcas	Root (W)	160 (24 hr)	50	*B. truncatus*	Not studied	32
Jatropha curcas	Root (A)	100 (24 hr)	100	*B. truncatus*	Not studied	32
Jatropha curcas	Seeds(W) field trial)	4 g/m^2 (2 weeks)	90 +	*O. quadrasi*	Not studied	142
LEGUMINOSAE						
Derris elliptica	Root (W)	20 ppm (24 hr)	100	*B. (P.) globosus*	Not studied	86
Entada phaseoloides	Bark (B)	3.6, 5.8 (48 hr)	100	*O. quadrasi*	Not studied	140

Table I Cont.

Plant species, by family	Parts tested (extract*)	Concentration tested (time of exposure)	Mortality (%)	Target species	Other effects	References
Entada phaseoloides	Bark, (E, B, EA, W)	500 + (48 hr)	50	*O. quadrasi*	Not studied	140
Entada phaseoloides	Bark (B)	1.3 (48 hr)	50	Fish *(Oryzias latipes)*	Not studied	140
Entada phaseoloides	Bark (B, field trial)	40 g/m^2 (1 week)	22–50	*O. quadrasi*	Not studied	140
Neorautenenia pseudopachyrhizus	Root (W)	500 ppm (24 hr)	100	*B. (P.) globosus*	Not studied	126
Neorautenenia pseudopachyrhizus	Root (W, field trial)	73.5 lbs / 2350 m^3 of water	50	*B. (P.) globosus*	Not studied	126
Piptadenia macrocarpa	Bark (W)	1000 ppm (24 hr)	100	*B. glabrata*	Not studied	10
Pithecellobium multiflorum	Seeds (W)	100 ppm (24 hr)	90	*B. stramina*	Not studied	106
Stenolobium velutinum	Bark, leaves (W)	1000 ppm (24 hr)	100	*B. glabrata*	Not studied	10
Stenolobium velutinum	Branches, fruit (W)	1000 ppm (72 hr)	100	*B. stramina*	Not studied	10
MALPIGUIACEAE						
Brysonima sericeae	Bark (W)	1000 ppm (8 hr)	100	*B. stramina*	Not studied	117
MIMOSACEAE						
Acacia dudgeoni	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Calliandra portoricensis	Root (M)	20 ppm (24 hr)	100	*B. globosus*	Not studied	5
Distrochachys glomerata	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Tetrapleura tetraptera	Fruit (M)	1–3 ppm (24 hr)	„molluscicidal"	*B. globosus*	Not studied	6
Tetrapleura tetraptera	Fruit (W)	10 ppm (?)	„molluscicidal"	*B. globosus, Lanistes* sp., *B. forskalii*	Low mammalian toxicity and no phytotoxicity	6
OCHNACEAE						
Lophira alata	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
OLACACEAE						
Ximenia americana	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
OPILIACEAE						
Agonandra brasiliensis	Bark (W)	1000 ppm (2 hr)	100	*B. stramina*	Not studied	117
Agonandra brasiliensis	Bark, root (A)	100 ppm (24 hr)	No effect	*B. stramina*	Not studied	117
PHYTOLACCACEAE						
Phytolacca dodecandra	Berries *(dry fruit) (W)*	18–29 ppm (24 hr)	90	*B. truncatus sericinus,*	Not studied	54, 58
				B. pfeifferi,		
				L. natalensis,	Not studied	54, 58
Phytolacca dodecandra	Berries (B)	100 ppm (24 hr)	No effect	Eggs of *Bulinus* sp.	Not studied	57
Phytolacca dodecandra	Berries (B)	100 ppm (24 hr)	No effect	Eggs of *B. glabrata*	Not studied	57
Phytolacca dodecandra	Berries (B)	100 ppm (24 hr)	active	Eggs of *Lymnaea* sp.	Not studied	57
Phytolacca dodecandra	Berries (W)	2 g/kg of body weight (?)	No effects	Sheep, dogs	Not studied	77
Phytolacca dodecandra	Berries (W)	3–10 ppm (24 hr)	90	*Tilapia nilotica*	Not studied	41
Phytolacca dodecandra	Berries (W)	11 ppm (24 hr)	90	Small *Barbus* sp. (catfish)	Not studied	41
Phytolacca dodecandra	Berries (W)	19 ppm (24 hr)	90	Small *Cyprinus carpio* (carp), tadpoles	Not studied	41
Phytolacca dodecandra	Berries (W)	6 ppm (24 hr)		*Lymnatis nilotica* (leech)	Not studied	41
Phytolacca dodecandra	Berries (W)	54–110 ppm (24 hr)	90	Zoo- and phyto-plankton (8 species)	Not studied	41
Phytolacca dodecandra	Berries (W)	11–68 ppm (24 hr)	90	*Anopheles* larvae	Not studied	41, 61
Phytolacca dodecandra	Berries (W)	25 ppm (24 hr)	90	*Simulium* larvae	Not studied	13
Phytolacca dodecandra	Berries (B)	1–80 ppm (24 hr)	90	*Aedes aegyti* *Anopheles sp., Culex pipiens*	Not studied	119
Phytolacca dodecandra	Berries (B)	n (24 hr)	90	*B. glabrata*	Not studied	58
Phytolacca dodecandra	Berries (B)	3.2 ppm (24 hr)	90	*B. alexandrina*	Not studied	58
Phytolacca dodecandra	Berries (B)	2.8 ppm (24 hr)	90	*B. truncatus*	Not studied	58
Phytolacca dodecandra	Berries (B ?)	4.6 ppm (48 hr)	90	*O. nosophora*	Not studied	139
Phytolacca dodecandra	Berries (B)	3.9 ppm (24 hr)	90	*B. (P.) nasatus*	Not studied	16
Phytolacca dodecandra	Berries (B)	5.2 ppm (24 hr)	90	*B. pfeifferi*	Not studied	16

Table I Cont.

Plant species, by family	Parts tested (extract*)	Concentration tested (time of exposure)	Mortality (%)	Target species	Other effects	References
Phytolacca dodecandra	Berries (B)	5.9 ppm (24 hr)	90	*B. choanomphala*	Not studied	16
Phytolacca dodecandra	Berries (water/ fermentation)	4 ppm (24 hr)	100	*B. glabrata*	Not studied	64
Phytolacca dodecandra	Berries (W, field trial)	50–100 ppm (3–6 hr)	Most snails killed	*B. truncatus sericinus, B. pfeifferi*	Not studied	54
Phytolacca dodecandra	Berries (W, field trial)	80–100 ppm (6–8 hr)	Elimination of *S. mansoni* infected *B. pfeifferi* for 7 weeks	*B. pfeifferi, Lymnaea* sp.	Reduction in the incidence of *S. mansoni* infections, in 1–6 yr. old children from 50 %–15 %; small fish, leeches, tadpoles killed	62
Phytolacca isocandra	Fruit (W)	200 ppm (24 hr)	100	*Lymnaea cubensis, L. columella*	Not studied	82
Phytolacca rivinoides	Fruit (W)	200 ppm (24 hr)	100	*L. cubensis, L. columella*		
PIPERACEAE						
Piper tuberculatum	Rootbark	10 ppm (24 hr)	„molluscicidal"	*B. glabrata*	Not studied	105
POLYGALACEAE						
Securidaca longepedunculata	Root (W)	350 ppm (24 hr)	100	*Taphia* (sic) *glabrata*	Not studied	15
POLYGONACEAE						
Polygonum senegalense	Leaves (W)	5000 ppm (24 hr)	„molluscidal"	*B. pfeifferi, L. natalensis*	Not studied	30
Polygonum senegalense	Seeds, leaves (E)	25 ppm (8 hr)	100	*B. pfeifferi, B. sudanica*	Not studied	30
RHAMNACEAE						
Maesopsis emenii	Root (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
ROSACEAE						
Acioa spp.	Stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
RUBIACEAE						
Morinda lucida	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Randia nilotica	Fruit (S:P, E)	60 ppm (24 hr)	100	*B. pfeifferi*	Not studied	32
		20 ppm (24 hr)	100	*B. truncatus*		
Randia nilotica	Root bark (S:P, E)	80 ppm (24 hr)	100	*B. pfeifferi*	Not studied	32
Randia nilotica	Fruit (W)	40 ppm (24 hr)	50	*B. truncatus B. pfeifferi*	Not studied	32
Randia nilotica	Root bark (W)	40 ppm (24 hr)	100	*B. truncatus B. pfeifferi*	Not studied	32
Rothmania whitefieldii	Leaves, stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
SAPINDACEAE						
Paullinia pinnata	Bark, leaves (W)	1000 ppm (24 hr)	100	*B. glabrata*	Not studied	10
Paullinia pinnata	All parts (W)	1000 ppm (24 hr)	No effect	*L. cubensis, L. columella*	Not studied	82
Sapindus saponaria	Berries (W)	100 ppm (40 hr)	100	*B. (P.) globosa*	Not studied	86
Sapindus saponaria	Berries (W)	150 ppm (24 hr)	100	*B. (P.) globosa*	Not studied	86
Sapindus saponaria	Berries (hot W, A)	25 ppm (6 hr)	94	*B. glabrata, L. cubensis*	Not studied	129
Sapindus saponaria	Berries (hot W, A)	25 ppm (6 hr)	100	17 species of Protozoa	Not studied	129
Sapindus saponaria	Berries (hot W, A)	25 ppm (6 hr)	60–100	3 species of Crustacea	Not studied	129
Sapindus saponaria	Berries (hot, W, A)	25 ppm (6 hr)	No effects	*Anopheles* sp., *Culex* sp., 11 other insect species	Not studied	129
Sapindus saponaria	Berries (hot W, A)	40–50 ppm (6 hr)	Lethal	Fish *(Lebistes reticulatus, Rivulus bondi)*	Not studied	129
Sapindus saponaria	Berries (W)	6.6 g/kg of body weight	No effects	Mice		129

Table I Cont.

Plant species, by family	Parts tested (extract*)	Concentration tested (time of exposure)	Mortality (%)	Target species	Other effects	References
Sapindus saponaria	Berries (W)	500 ppm (24 hr)	100	*B. (P.) africanus*	Not studied	88
Sapindus saponaria	Berries (W, field trial)	1 kg fruit pulp/m^3 water	Snail reduction for 10 days	*B. (P.) africanus*	Not studied	88
SOLANACEAE						
Solanum nodiflorum	All parts (W)	100 ppm (24 hr)	100	*L. cubensis, L. columella*	Not studied	82
Solanum nodiflorum	Roots, leaves (W)	50 ppm (24 hr)	100	*L. columella*	Not studied	83
Solanum nodiflorum	Roots, leaves (W)	100 ppm (24 hr)	100	*B. glabrata*	Not studied	83
Solanum nodiflorum	Roots, leaves (W)	100 ppm (24 hr)	100	*L. cubensis*	Not studied	83
Solanum nodiflorum	Roots, leaves (W)	100 ppm (24 hr)	85	*Physa cubensis*	Not studied	83
Solanum nodiflorum	Roots, leaves (W)	100 ppm (24 hr)	No effect	*Marisa cornuarietis, Tarebia granifera*	Not studied	83
Solanum mammosum	Fruits (M)	25 ppm (24 hr)	95	*L. cubensis*	Not studied	8
STYRAXAXEAE						
Styrax officinalis	Fruit (?)	100 ppm (24 hr)	100	*Bulinus* sp.	Not studied	110
UMBELLIFERAE						
Amni majus	?	2 ppm (?)	9–69	*Biomphalaria* sp.	Not studied	118
VERBENACEAE						
Vitex oxycuspis	Stem (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
XYRYDACEAE						
Xiris anceps	Leaves (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
ZYGOPHYLLACEAE						
Balanites aegyptiaca	Fruit (W)	5.2 g/30 liters of water (12 hr)	100	*Bulinus planorbis* (sic)	Kills fish, tadpoles	12
Balanites aegyptiaca	Fruit (W)	5.2 g/30 liters of water (1 hr or less)	100 (?)	*S. haematobium* cercariae	Not studied	12
Balanites aegyptiaca	Fruit (W)	1:860 (48 hr)	100	*B. glabrata* (?)	Not studied	99
Balanites aegyptiaca	Bark (W)	1:2600 (1 week)	100	*B. glabrata* (?)	Not studied	99
Balanites aegyptiaca	Fruit (W, field trial)	Fruits dropped from trees (?)	15–75	*B. glabrata* (?)	Low fish toxicity	99
Balanites aegyptiaca	Fruit (M)	100 ppm (24 hr)	100	*B. globosus*	Not studied	5
Balanites maughamii	Fruit (W)	1 fruit/100000 cc of water (24 hr)	Molluscicidal	*B. (P.) africanus, L. natalensis*	Kills cercariae, tadpoles, mosquito larvae	131

*A = "alcohol"
B = butanol
Be = benzene
C = chloroform
E = ethanol
EA = ethyl-acetate
Er = ether
H = hexane
M = methanol
P = petroleum
W = water
S = successive extractions

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