Pistia stratiotes (Jalkumbhi)

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ABSTRACT

Pistia stratiotes (Family: Araceae) is commonly used in Ayurvedic medicine. This review article is a compilation of all the updated information on its phytochemical and pharmacological activities, which were performed by different methods. Studies indicate that *P. stratiotes* possesses diuretic, antidiabetic, antidermatophytic, antifungal, and antimicrobial properties. These results are very encouraging and indicate that this plant should be studied more extensively to confirm the reproducibility of these results and also to reveal other potential therapeutic effects, along with some "leads" with possible isolation of active biomoieties and their mechanism of action.

Key words: Pharmacological activities, phytochemistry, *pistia stratiotes*

INTRODUCTION

Pistia stratiotes, also known as Jalkumbhi, is an aquatic plant, stoloniferous, floating on lakes, streams, and stagnant water ponds and in lime-rich water, throughout India. It is distributed in the tropical and subtropical region of Asia, Africa, and America. Four varieties are distinguished. The Indian variety is known as var. *cuneta*. It is propagated by seeds or more rapidly by stolons. It forms a dense mat on the water surface and causes serious clogging on water ways. It is also responsible for harboring mosquito larvae, which carry the filarial parasites. It flowers in hot season and fruits appear after the rain.[1]

TAXONOMICAL CLASSIFICATION

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Alismatoles
Family: Araceae
Genus: *Pistia* L.
Species: *P. stratiotes*

BOTANICAL DESCRIPTION

P. stratiotes is a floating, stoloniferous herb found in ponds and streams almost throughout India upto a height of 1000 m. Leaves are green in color, odorless, and bitter in taste. The leaves are approximately 13cm long and 17cm wide and of fan-shaped having parallel venation, blunt apex, and entire margin.

A large number of medicinal properties are attributed to the plant, particularly the leaves. The plant is considered antiseptic, antitubercular, and antidysentric. In Gambia, the plant is used as an anodyne for eyewash. Juice of plant is used by Mundas in ear complaints. The ash of plant is applied to the ringworm of the scalp. Leaves are used in eczema, leprosy, ulcers, piles, and syphilis. Juice of leaves boiled in coconut oil is applied externally in chronic skin diseases.[2]

The Plant is bitter, pungent flavored having cooling, laxative property. It is useful in "Tridosha," fever, and diseases of blood. The root is laxative, emollient, and diuretic. Leaves infusions have been mentioned in the folklore to be used for dropsy, bladder complaints, kidney afflictions, hematuria, dysentery, and anemia.

Part used

Whole plant

Synomyms

Hindi, Jalkumbhi; English, Shellflower; water cabbage; Bengali, Takapana; Gujrati, Jalashamkhala; Tamil, Akasatamari; and Oriya, Borajhanji.

PHYTOCHEMISTRY

The biologically active chemical constituents of *P. stratiotes* are alkaloids, glycosides, flavonoids, and steroids. An analysis of leaves and stems revealed the following: moisture 92.9%, protein 1.4%, fat 0.3%, carbohydrate 2.6%, fibers 0.9%, ash 1.9%, calcium 0.2%, phosphorus 0.06%. Leaves are rich in vitamin A

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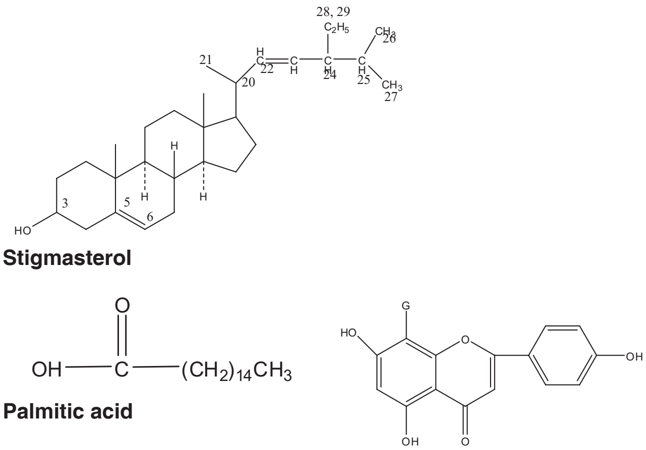

Stigmasterol

Palmitic acid

Vitexin

Figure 1: Phytoconstituents of *Pistia stratiotes L.*

and C, and also contain vitamin B. The ash is rich in potassium chloride and sulfate. Stigmasta-4,22-dien-3-one, stigmasterol, stigmasteryl stearate, and palmitic acids are reported in *P. stratiotes*. Plant gave 2-di-C-glcosylflavones of vicenin and lucenin type, anthocyanin-cynidin-3-glucoside, luteolin-7-glycoside and mono-C-glcosyl flavones – vitexin and orientin [Figure 1].[3]

PHARMACOLOGICAL ACTIVITIES

Although lot of pharmacological investigations have been carried out based on the ingredients present in the said plant, but a lot more can still be exploited and utilized. A summary of the findings of these studies is presented below.

Antidermatophytic activity

Methanolic extract of the plant *P. stratiotes* was found to be dermatophytes *Tricophyton rubrum*, *Microsporum Gypseum*, and *Epidermophyton floccosum* with MIC against *M. gypseum* and *M. nanum*. It was also seen that the *Trichophyton* and *Epidermophyton* spp. are more resistant to the extract and were inhibited at a higher dosage compared to *Microsporum* spp.[4]

Antifungal activity

P. stratiotes leaves possess antifungal properties which explain the use of plant in folk medicines for the treatment of various diseases.[4]

Calcium channels involved in calcium oxalate crystal formation in specialized cells

P. stratiotes produces large amount of Ca-oxalate crystals in specialized cells called crystal idioblasts. The results demonstrate that Ca-oxalate crystals idioblasts are enriched, relative to mesophyll cells in dihydropyridine type calcium channels and that activity of these channels is important to transport and accumulation of calcium is required for crystal formation.[5]

Calcium channel blocking activity and antimicrobial activity

Pharmacological activities of *P. stratiotes* were studied and Ca channel blocking activity of methanolic extract of a whole plant was demonstrated using isolated segments of rabbit jejunum and confirmed via inhibition by pretreatment with verapamil. It was seen that plant extract caused a decrease in blood pressure in anesthetized rat. After 10 μg of extract, systolic and diastolic blood pressures fell by 18% and 10%, respectively. Further doses of plant extract produce slight decreases in BP in anesthetized rats. The systolic, diastolic, and mean blood pressures before the extract were all significantly higher (P<0.001) than those the administration of extract. It was seen that the methanolic extract of *P. stratiotes* showed stronger and broader spectrum of antimicrobial activity as compared to hexane extract. It was seen that extract of *P. stratiotes* is able to lower the level of thyroid hormones and it may also be concluded that plant extract may regulate hyperthyroidism also.[6]

L-Ascorbic acid and L-galactose sources for oxalic acid and Ca-oxalate

Keates reported that *Pistia stratiotes* L. plants were labeled with [^{14}C]oxalic acid, L-[1-^{14}C]ascorbic acid, L-[6-^{14}C]ascorbic acid,D-[1-^{14}C]erythorbic acid, L-[1-^{14}C]galactose, or [1-^{14}C] glycolate. Specific radioactivities of L-ascorbic acid (AsA), free oxalic acid(OxA) and calcium oxalate (CaOx) in labeled plants were compared. Samples of leaf tissue were fixed for microautoradiography and examined by confocal microscopy. Results demonstrate a biosynthetic role for AsA as precursor of OxA and its crystalline deposition product, CaOx, in idioblast cells of P. stratiotes and support the recent discovery of Wheeler, Jones and Smirno.[34]

Biological control of water lettuce, *P. stratiotes* (Araceae), in South Africa

Water lettuce, *P. stratiotes* L., is a free-floating aquatic weed that is, as yet, of relatively minor importance in South Africa. The availability of agents that had proved successful in other countries prompted the importation of a weevil, *Neohydronomous affinis* (Hustache), from Brazil via Australia into South Africa for biological control of the weed. The introduction has been successful particularly on motionless water bodies where rapid and extreme reductions in weed density have been achieved. The weevils have been less successful on fast-flowing rivers where plants with weevil larvae are continually washed downstream, thus diluting the populations of *N. affinis*, especially during floods. The recently initiated biological control program against *P. stratiotes* in South Africa is reviewed.[8]

Axenic culture of *P. stratiotes* for use in plant biochemical studies

Free-floating aquatic plants are useful in studies of plant biochemistry. Their value lies in the fact that they are naturally adapted to growth on liquid media, which can be precisely manipulated. Critical biochemical studies require axenic plants free of contaminating organisms, which contribute unwanted chemical products or bind/metabolize added compounds. Axenic plants of *Lemna*, *Spirodela*, and *Wolffiella* spp. have been available for some time. Access to axenic cultures of the free-floating aquatic plant, *P. stratiotes* L., and Araceae (water lettuce) would provide a model more representatives of higher and terrestrial plants (leaves, stems, stolons, multiple roots). Our choice of *P. stratiotes* focuses on its value as a model to study oxalic acid formation and calcium regulation as related to calcium oxalate production. To this end, we have developed axenic *Pistia* cultures and compared nonaxenic plants grown in greenhouse conditions to the axenic plants in terms of organic acid content and morphology/anatomy. Axenic *Pistia* were comparable to greenhouse-grown plants, the only difference being the smaller size of axenic plants. This study demonstrates the suitability of axenic *Pistia* for biochemical research and also indicates that such plants will be very useful in studies of bioremediation and other processes in aquatic systems.[9]

Competition for space between *Eichhornia crassipes* (Mart.) Solms and *P. stratiotes* L. cultured in nutrient-enriched water

The interrelationship between two free-floating aquatic macrophytes, *Eichhornia crassipes* (Mart.) Solms and *P. stratiotes* L, was investigated using a reciprocal replacement series for the intermixed combinations. The carrying capacity for each species was investigated in monoculture. The plants were cultured in outdoor tanks in Gainesville, Florida, where nutrient-enriched water was replenished at weekly intervals.

E. crassipes showed dominance over *P. stratiotes* when the species were grown together. Interaction between the two species for growth space became apparent within the first month of the experimental period. The luxuriant growth and high plasticity of *E. crassipes* plants enabled them to grow above the *P. stratiotes* plants, thus shading and stressing them. Higher concentrations of nitrogen (N) (by about twofold) were accumulated in the shoots of *E. crassipes* than in its roots, whereas N accumulation in the roots and shoots of *P. stratiotes* was similar. The N content of *E. crassipes* shoots increased throughout the experimental period approximately sixfold, while the N content of roots increased twofold. Phosphorus accumulation was equally distributed between the roots and shoots of both species.[10]

Seasonal growth of *P. stratiotes* L. in South Florida

Two populations of *P. stratiotes* L. in an unused aquaculture pond and a roadside drainage ditch were sampled monthly for 1.5 years to examine seasonal trends in leaf area, leaf and plant densities, leaf and root biomasses, and flowering. Biomasses and leaf areas were sharply depressed by winter cold, especially by subfreezing temperatures. Spring regrowth occurred by budding and the proliferation of small plants. From late-spring through mid-summer, leaf size and plant biomass increased and plant density decreased; these variables did not change markedly between August and December. In both populations, flowering occurred synchronously during December, but no sexual reproduction was observed. Winter cold is a major determinant of growth patterns in south Florida, but local conditions are also important.

Measurements from the day of unfurling until subsidence into the water showed that leaves reached an average length of 15.3 cm after 2 weeks and declined toward the water at a rate of 2.9° per day.[11]

Survival and expansion of *P. stratiotes* L. in a thermal stream in Slovenia

Successful winter survival of a tropical plant *P. stratiotes* in a natural thermal stream in Slovenia has been studied and reported. Only 2 years after its first occurrence in 2001, *P. stratiotes* managed to cover most of the water body where the thermal springs cause an elevated temperature (>17°C year round). Enhanced biomass production of this invasive species took place in spring and summer and new stolons were formed at the end of the vegetation season. Over the winter, older rosettes decayed and only small rosettes survived besides new rosettes formed from stolons. Plants developed flowers in April through August. Observations in December revealed viable seed production and seed presence in the sediment survival trait.[12]

Host specificity and biology of *Spodoptea pectinicornis* (Lepidoptera: Noctuidae), a biological control agent of water lettuce (*P. stratiotes*)

The noctuid *S. pectinicornis* (Hampson) from southeast Asia was studied in quarantine for potential use as a biological control agent of the floating aquatic weed water lettuce, *P. stratiotes* L. Host-specificity tests were conducted on 70 plant species in 32 families. First instars fed slightly on five plant species and moderately on one. Third instars fed slightly on seven, moderately on five, and heavily on three plant species. In all tests, no larvae lived longer than 6 days or developed to the next stage except those on impatiens (*Impatiens balsamina* L.). In whole-plant tests of impatiens, larvae fed for several weeks, but were unable to complete development. In multichoice oviposition tests, moths laid over 70% of their egg masses on water lettuce, 21% on nonplant surfaces, four masses on eggplant (*Solanum melongena* L.), and one mass each on four other plant species. No eggs were laid on impatiens. The inability of larvae to develop to the next stage except on whole plants of impatiens, on which they did not advance to the pupal stage, and the nonchoice of impatiens for oviposition indicate the safety of *S. pectinicornis* for release. Species from genera with mostly polyphagous members should not be rejected from consideration as biological control agents of weeds without testing. Areas other than the apparent center of origin should also be explored to discover newer insect–plant associations. Information on the biology of *S. pectinicornis* is also presented.[13]

Influence of temperature on biogas production from *P. stratiotes*

P. stratiotes, an aquatic weed, was investigated as a substrate for biogas production. Experiments were carried out as batch runs in laboratory-scale digesters with the addition of inoculum (digested cattle manure). Gas yields were in the range of 533–707 lkg^{-1} VS (STP) and 21–28 lkg^{-1} fresh weight of *P. stratiotes*, with 30 days digestion time at temperatures of 29.5, 33.0, and 37.5°C, respectively. The average methane content was 58–68%. Due to its high biodegradability (approximately 83–99% of VS), *P. stratiotes* is very suitable as a substrate for biogas production.[14]

Ethanol production from candidate energy crops: Water hyacinth (*Eichhornia crassipes*) and water lettuce (*P. stratiotes* L.)

Fermentation modes and microorganisms related to two typical free-floating aquatic plants, water hyacinth and water lettuce, were investigated for their use in ethanol production. Except for arabinose, sugar contents in water lettuce resembled those in water hyacinth leaves. Water lettuce had slightly higher starch contents and lower contents of cellulose and hemicellulose. A traditional strain, *Saccharomyces cerevisiae* NBRC 2346, produced 14.4 and 14.9 g l^{-1} ethanol from water hyacinth and water lettuce, respectively. Moreover, a recombinant strain, *Escherichia coli* KO11, produced 16.9 and 16.2 g l^{-1} ethanol in the simultaneous saccharification and fermentation mode (SSF), which was more effective than the separated hydrolysis and fermentation (SHF) mode. The ethanol yield per unit biomass was comparable to those reported for other agricultural biomasses: 0.14–0.17 g g-dry^{-1} for water hyacinth and 0.15–0.16 g g-dry^{-1} for water lettuce.[15]

Mosquito development in a macrophyte-based wastewater treatment plant in Cameroon (Central Africa)

Macrophyte-based wastewater treatment systems are recognized as an alternative for sewage purification in developing countries. Unfortunately, they also represent a favorable breeding ground for mosquitoes, a serious drawback that should be addressed despite the good promise of this technology.

A 1-year study of mosquito production in seven ponds of a *P. stratiotes*-based domestic wastewater treatment plant in Cameroon revealed that approximately 43 imagoes/m^2 per day rose up, among which 54% were female. *Mansonia* and *Culex* were the main breeding genera with about 55% and 42% of the total imagoes, respectively. *Culex* bred mostly in the first three ponds (B1–3), characterized by a high organic pollution. *Mansonia* occurred in great number in the later ponds (B4–7), where the water quality was rather better and the roots of *P. stratiotes* well developed, thus permitting the fixation of a great number of larvae to the macrophyte roots. Although representing a favorable breeding ground for mosquitoes, only 0.02% of captured imagoes were *Anopheles gambiae*, suggesting that this wastewater treatment plant does not significantly contribute to the development of the malaria vector in this area.[16]

Cadmium and chromium removal kinetics from solution by two aquatic macrophytes

As per reports, the aim of the work was to determine chromium and cadmium bioaccumulation processes of two free-floating macrophytes commonly used in wetlands for water treatment: *Salvinia herzogii* and *P. stratiotes*. Metal removal from the solution involves two stages: a fast one and a slow one. The fast stage of the Cd uptake is significantly different for each species, while it is not significantly different in Cr uptake. The most important processes of Cd uptake are biological ones in *S. herzogii* and adsorption, chelation, and ionic exchange are in *P. stratiotes*. The main processes of Cr uptake in both macrophytes are adsorption, chelation, and ion exchange. The slow stage is different for each species and metal. Cr precipitation induced by roots occurs in *P. stratiotes*. Cr uptake through leaves is probably the main cause of the increase in Cr in the aerial parts of *S. herzogii*.

Cd uptake processes are biological processes in *S. herzogii* and adsorption, chelation, and ionic exchange are in *P. stratiotes*, whereas Cr uptake processes in both macrophytes are adsorption, chelation, and ion exchange.[17]

Mercury uptake and accumulation by four species of aquatic plants

The effectiveness of four aquatic plants including water hyacinth (*Eichornia crassipes*), water lettuce (*P. stratiotes*), zebra rush (*Scirpus tabernaemontani*), and taro (*Colocasia esculenta*) were evaluated for their capabilities in removing mercury from water. The plants were exposed to concentrations of 0, 0.5, or 2mg/L of mercury for 30 days. Assays were conducted using both Microtox® (water) and cold vapor Atomic Absorption Spectroscopy (AAS) (roots and water). The Microtox® results indicated that the mercury-induced acute toxicity had been removed from the water. AAS confirmed an increase in mercury within the plant root tissue and a corresponding decrease in mercury in the water. All species of plants appeared to reduce mercury concentrations in the water via root uptake and accumulation. Water lettuce and water hyacinth appeared to be the most effective, followed by taro and zebra rush, respectively.

Four species of aquatic plants reduced mercury in water.[18]

The productivity of *P. stratiotes* L. in a eutrophic lake

In Nigeria, most of the water bodies receiving organic pollution promote the growth of an aquatic weed, *P. stratiotes* L. A study has been made of the occurrence of this weed in one of the eutrophic lakes, of its growth characteristics and of its possible utilization. As it spreads on the water surface, the weed removes 83.1% BOD, 93.3% ammonia nitrogen, and 75.0% phosphorus. It also produces a biomass of about 2375 kg/ha and prevents evaporation losses by about 20%. Its dry matter contains about 14% protein.[19]

Steroid from *P. stratiotes*

A novel stigmastane, 11-hydroxy-24*S*-ethyl-5-cholest-22-en-3,6-dione, has been isolated from the aquatic plant *P. stratiotes*. The structure determination was accomplished by spectroscopic methods. A revision of the NMR assignments of an analogous cholestane sterol is also reported.[20]

Calreticulin is enriched in the crystal idioblasts of *P. stratiotes*

Calreticulin (CRT) has the highest calcium-binding capacity of the endoplasmic reticulum (ER) proteins found thus far in plants. In this study, we isolated cDNAs encoding CRT from

P. stratiotes L. (*Araceae*) and analyzed the temporal and spatial patterns of CRT expression in leaves. Northern analysis showed that young leaves had the highest CRT transcript levels, which decreased as the leaves matured. To investigate differences in the expression and cellular localization of CRT, *in situ* hybridization and immunolocalization were performed. We observed an enrichment of both CRT transcript and protein in a unique cell type called the crystal idioblast. Crystal idioblasts are specialized cells that act as calcium sinks in tissues such as leaves. Subcellular localization showed that the CRT protein partitioned into the ER of the crystal idioblasts. At higher resolution, using transmission electron microscopy (TEM), it appeared that the CRT protein was more abundant in "dilated" regions of the ER. Although the specific role(s) CRT plays in the idioblast remains to be determined, we hypothesize that this high-capacity calcium-binding protein functions in the regulation of intracellular idioblast calcium levels.[21]

Endoplasmic reticulum subcompartments are involved in calcium sequestration within raphide crystal idioblasts of *P. stratiotes* L

To regulate bulk Ca^{2+} levels, many plants evolved specialized Ca^{2+} oxalate accumulating cells called crystal idioblasts. The crystal idioblast appears to have modified some of its cellular components to accommodate the large fluxes of Ca^{2+} that occur during calcium oxalate deposition. In this study we examine the modified ER and its involvement in Ca^{2+} sequestration. Using a variety of microscopy techniques, we observe that the crystal idioblast of *P. stratiotes* possesses an elaborate network of ER with unique swollen regions. Light microscopy studies, using chlortetracycline and Calcium Green 2, revealed that idioblast ER contains an abundance of calcium. TEM studies, using the potassium pyroantimonate technique, showed that the Ca^{2+} accumulated primarily in the swollen regions. We hypothesize that these swollen areas function as specialized Ca^{2+} storage sub\ compartments. Whether these subcompartments are required for proper ER functions or whether they are part of the Ca^{2+} transport system involved in calcium oxalate formation remains to be determined.[22]

Cadmium uptake by floating macrophytes

Cd uptake capacity of a group of floating macrophytes (*S. herzogii, P. stratiotes*, *Hydromistia stolonifera*, and *Eichhornia crassipes*) was determined in outdoors experiments during the lowest temperature period of the year. Although all studied species were highly efficient in the Cd uptake, *P. stratiotes* was selected for further research because of its superior performance and higher average relative growth rate. Cadmium % removal by *P. stratiotes* was greater in the first 24h of the experiments (63%, 65%, 72%, and 74% of the added Cd for 1, 2, 4, and 6 mg Cd l^{-1}, respectively). After 31 days of growth, *P. stratiotes* efficiently removed Cd at the studied concentrations. The macrophyte was able to keep its capacity for Cd removal even though some toxicity symptoms appeared at 4 and 6 mg l^{-1} Cd. The greater the initial concentration, the greater the Cd bioaccumulation rates. The increase in Cd concentration in plant tissues occurred especially in roots and was linearly related to the quantity of Cd added. Cd sorption by roots is faster than translocation to the plant aerial part and it occurs mainly during the first 24h.[23]

Kinetics of nitrate and ammonium uptake by the tropical freshwater macrophyte *P. stratiotes* L.

The kinetics of nitrogen uptake was examined for a common freshwater macrophyte *P. stratiotes*. Nitrate-nitrogen and ammonium-nitrogen uptake were monitored in response to a wide range of substrate concentrations. Nitrate uptake rates were higher after 24h of exposure to the nitrate source than immediately after exposure. The rate of uptake of nitrate-nitrogen was greater in the light than in the dark. Nitrate uptake followed a pattern which could be adequately described by the Michaelis–Menten expression. Ammonium-nitrogen uptake response to substrate concentration appeared to be linear. Rates of ammonium-nitrogen uptake were similar in the dark and in the light. For any given dissolved nitrogen concentration, the rate of ammonium-nitrogen uptake was greater than the rate of nitrate-nitrogen uptake.[24]

Chemical characterization of pressed fibrous residues of four aquatic weeds

As per reports, the pressed fibrous residues, generated as a by-product during the large-scale manufacture of leaf protein from four aquatic weeds, *P. stratiotes* L. var. *cuneata Engl.* (Araceae), *Nymphoides cristatum* (Roxb.), *O. Kuntze* (Gentianaceae), *Lemna perpusilla* Torr. (Lemnaceae), and *Allmania nodilflora* (L.), *R.Br. ex Hook.f.* (Amaranthaceae), were analyzed for their chemical and mineral composition. They were found to consist of lignin, cellulose, pentosan, lipid, pectin, and minerals. *P. stratiotes* is a rich source of cellulose (40.63%), *A. nodiflora* and *N. cristatum* contain pentosan and pectin (19.75% and 14.49%, respectively), while *L. perpusilla* shows comparatively larger amounts of minerals (ash content 15%). All the values obtained were compared with those of other similar aquatic weeds and agricultural wastes such as rice and wheat straw, grass, bagasse, etc., which are usually used in the preparation of silage, compost, biogas, and several other products.[25]

Production of viable seeds by water lettuce, *P. stratiotes* L., in Australia

Seeding by water lettuce, *P. stratiotes* L., was briefly reviewed, and production and germination of seeds in Australia was recorded for the first time. Seeds germinated on wet filter paper and under water in continuous light, intermittent light, or continuous dark. Germination took longer and percentage germination was lower in continuous dark than in the light treatments. Damaging the seed coat to facilitate entry of water reduced time to germination in the light treatments.[26]

Seed production by *P. stratiotes* L. (water lettuce) in the United States

P. stratiotes L. (water lettuce) reportedly does not produce fruits and seeds in the United States. However, the authors discovered water lettuce fruits and seedlings at Loxahatchee National

Wildlife Refuge, Palm Beach County, Florida. In April 1987, 95% of this population consisted of seeds. Forty percent of the 267 ramets per square meter of mat held fruits and the mat averaged 726 seeds per square meter. Sediments held 4196 seeds per square meter. Germination experiments showed that over 80% of the seeds were viable, a much greater proportion than reported in Brazil. Since the initial discovery, authors reported seeds at many sites throughout south Florida and have concluded that seed germination is an important factor in the dynamics of some water lettuce populations in United States.[27]

The flavonoid chemistry of *P. stratiotes* L. and the origin of the Lemnaceae

Many workers have considered *Pistia* an evolutionary link between the Aroids and the Lemnaceae. The Lemnaceae have a rich flavonoid chemistry, which becomes less complex as one follows the morphological reduction from *Spirodela* to *Lemna* and thence to *Wolffiella* and *Wolffia*. *Pistia* contains large amounts of two di-*C*-glycosylflavones of the vicenin and lucenin type plus two unidentified compounds which are probably their derivatives, lesser amounts of the anthocyanin cyanidin-3-glucoside and a luteolin-7-glycoside, and traces of the mono-*C*-glycosylflavones vitexin and orientin. Although there is no close correspondence between the specific flavonoids accumulated by *Pistia* and those found in the morphologically more complex members of the Lemnaceae, *Pistia* appears to have the biochemical pathways to most flavonoid types found in the Lemnaceae. This is in agreement with the concept that the Lemnaceae may have arisen from a *Pistia*-like ancestor.[28]

Biogas production from the aquatic weed *Pistia* (*P. stratiotes*)

P. stratiotes, an aquatic weed, was investigated as a substrate for biogas production in batch digestion. An inoculum was necessary to obtain biogas production from the weed. With *Pistia* only, production of carbon dioxide alone was high during the first 5 days of digestion but began to level off thereafter. With inoculated *Pistia*, a high rate of biogas production was sustained for nearly 10 days and the average methane content was 58–68%. The digesters charged with *Pistia* alone had significant concentrations of propionic, butyric, isobutyric, valeric, and isovaleric acids. These acids were not present in detectable concentrations, in the digesters running with inoculated *Pistia*, except during the first 4 days of the digestion when propionic acid was formed. When an inoculum was added to a "soured" digester the performance of the latter improved dramatically.[29]

Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes

The authors investigated effectiveness of three aquatic macrophytes. *P. stratiotes* L. (water lettuce), *Spirodela polyrrhiza* W. Koch (duckweed), and *Eichhornia crassipes* were tested for the removal of five heavy metals (Fe, Zn, Cu, Cr, and Cd). These plants were grown at three different concentrations (1.0, 2.0, and 5.0 mg l^{-1}) of metals in laboratory experiment. Result revealed high removal (>90%) of different metals during 15 days experiment. Highest removal was observed on 12th day of experiment, and it decreased thereafter. Results revealed *E. crassipes* as the most efficient for the removal of selected heavy metals followed by *P. stratiotes* and *S. polyrrhiza*. Results from analysis confirmed the accumulation of different metals within the plant and a corresponding decrease of metals in the water. Significant correlations between metal concentration in final water and macrophytes were obtained. Plants have accumulated heavy metals in its body without the production of any toxicity or reduction in growth. Selected plants showed a wide range of tolerance to all the selected metals and, therefore, can be used for the large-scale removal of heavy metals from waste water.[30]

Chromium-induced lipid peroxidation in the plants of *P. stratiotes* L.: Role of antioxidants and antioxidant enzymes

In the plant, *P. stratiotes* L., the effect of different concentrations of chromium (0, 10, 40, 80, and 160 μM) applied for 48, 96, and 144 h was assessed by measuring changes in the chlorophyll, protein, malondialdehyde (MDA), cysteine, nonprotein thiol, ascorbic acid contents and superoxide dismutase (SOD), ascorbate peroxidase (APX), and guiacol peroxidase (GPX) activity of the plants. Both in roots and leaves, an increase in MDA content was observed with an increase in metal concentration and exposure periods. In roots, the activity of antioxidant enzymes, viz. SOD and APX, increased at all the concentrations of Cr at 144 h than their controls. The GPX activity of the treated roots increased with increase in Cr concentration at 48 and 96 h of exposures; however, at 144 h its activity was found declined beyond 10μM Cr. The level of antioxidants in the roots of the treated plant viz. cysteine and ascorbic acid was also found increased at all the concentrations of Cr at 144h than their respective controls; however, an increase in the nonprotein thiol content was recorded up to 40μM Cr followed by a decrease. The chlorophyll content decreased with increase in Cr concentrations and exposure periods. However, the protein content of both roots and leaves was found decreased with an increase in Cr concentrations at all the exposure periods except an increase recorded at 10μM Cr at 48h. In Cr-treated plants, the no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) for leaves chlorophyll and protein contents were 40 and 80μM Cr, respectively, after 48h exposure, while NOEC and LOEC for root protein content were 10 and 40μM, respectively, after 48 h. The analysis of correlation coefficient data revealed that the metal accumulation in the roots of the plant was positively correlated with antioxidant parameters except SOD after 48h of exposure and, however, negatively correlated with most of the parameters studied at 144h in both part of the plant. It may be suggested from the current study that toxic concentrations of Cr cause oxidative damage as evidenced by increased lipid peroxidation and decreased chlorophyll and protein contents. However, the higher levels of enzymatic and nonenzymatic antioxidants suggest the reason for tolerating higher levels of metals.[31]

Different compensatory mechanisms in two metal-accumulating aquatic macrophytes exposed to acute cadmium stress in outdoor artificial lakes

Mechanisms underlying cadmium (Cd) detoxification were compared in two aquatic macrophytes commonly used in phytoremediation, namely *P. stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms. To simulate Cd pollution in the open environment, plants growing in outdoor artificial lakes were exposed for 21 days to either 25 or 100 μM Cd, in two consecutive years. Toxicity symptoms were absent or mild in both species. Metal accumulation was much higher in the roots of *P. stratiotes*, whereas in *E. crassipes* a comparatively higher fraction was translocated to the leaves. In both species, Cd was neither included in phenolic polymers or Ca-oxalate crystals, nor altered the levels of Cd-complexing organic acids. Glutathione levels were constitutively remarkably higher and much more responsive to Cd exposure in *P. stratiotes* than in *E. crassipes*. Abundant phytochelatin synthesis occurred only in *P. stratiotes*, both in roots and in leaves. In *E. crassipes*, on the other side, the constitutive levels of some antioxidant enzymes and ascorbate were higher and more responsive to Cd than in *P. stratiotes*. Thus, in these two aquatic plants grown in the open, different detoxification mechanisms might come into play to counterbalance Cd acute stress.[32]

Effect of mercury on some aquatic plants

Three aquatic plants, *Hydrilla verticillata* Presl, *P. stratiotes* L., and *S. molesta* D.S. Mitchell, were treated with different concentrations of mercury ranging from 1 to 1000μg l^{-1} at three different exposure durations, i.e. 1, 3, and 5h. All were found to be severely affected by mercury. Foliar injury, chlorophyll content and phytomass showed perceptible effects with increasing exposure to the metal. In the case of floating plants, a positive relationship was obtained between *leaf injury index* (LII) and doses of the metal. The possible use of aquatic plants in general, and floating plants in particular, as simple bioassay material in biomonitoring and toxicity studies was discussed with special reference to LII as a simple biomonitoring parameter.[33]

Acylglycosyl sterols from *P. stratiotes*

Three new sitosterol acylglycosides have been isolated from the ethereal extract of the aquatic plant *P. stratiotes*. The structures sitosterol-3-*O*-[2',4'-*O*-diacetyl-6'-*O*-sterayl]-β-D -glucopyranoside, sitosterol-3-*O*-[2'-*O*-stearyl]-β-D -xylopyranoside and sitosterol-3-*O*-[4'-*O*-stearyl]-β-D-xylopyranoside have been defined by spectroscopic data and chemical conversion.[34].

CONCLUSION

This commonly available economical plant has a lot more to offer, in term of exploration of its prophylactic and therapeutic properties, as perceived by the authors, continued research work is highly recommended on this plant.

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