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REVIEW ARTICLE

Aquatic Plants *Pistia stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms: An Sustainable Ecofriendly Bioresources - A Review

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ABSTRACT

Aquatic plants have economic and environmental uses, depending on the natural characteristics. They proved to be the effective bioresources which are eco-friendly in nature. The floating aquatic hyper accumulating plants absorb or accumulate contaminants by their whole body. These commonly available economical plants have a lot of prophylactic and therapeutic properties for maintenance of good health and can also be exploited in the manufacture of drugs. The antimicrobial activity of the plant extracts and phytochemicals was evaluated with antibiotic susceptible and resistant microorganisms. Recently much attention has been paid to extracts and biologically active compounds isolated from plants species.

KEYWORDS

Bioresources, Phytochemicals, Prophylactic, Phytoremediation, *Eichhornia crassipes*, *Pistia Stratiotes*

INTRODUCTION

Bioresources refers to the total biological variation manifested as individual plants, animals or their genes, which could be taken by man for use as drugs, food, livestock feed, construction materials for shelter, environmental protection, etc or in the development of improved crops and animals for higher yield and tolerance to biotic and abiotic stresses.[1] Freshwater as well as seawater resources are being contaminated by various toxic elements through anthropogenic activities and from natural sources. Therefore, remediation of contaminated aquatic environment is important as it is for terrestrial environment. Phytoremediation of the toxic contaminants can be readily achieved by aquatic macrophytes or by other floating plants since the process involves biosorption and bioaccumulation of the soluble and bioavailable contaminants from water.[2] Several aquatic macrophytes and some other small aquatic floating plants have been investigated for the remediation of natural and wastewater contaminated with Cu(II), Cd(II) and Hg(II).[3,4,5]

In many cases, especially in tropical or subtropical areas, invasive plants such as the water hyacinth (*Eichhornia crassipes)* and water lettuce *(P. stratiotes L.)* are used in these phytoremediation water systems.[6,7]

This is because, compared to native plants, these invasive plants show a much higher nutrient removal efficiency with their high nutrient uptake capacity, fast growth rate, and big biomass production.[8]

Plants have bioactive compounds like alkaloid, tannins, flavonoids and phenolic that produce definite physiological actions in the body and therefore could be used to treat various ailments.

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Botanical Description

Eichhornia crassipes (Mart.) Solms

Eichhornia crassipes (Mart.) Solms belongs to the family Pontederiaceae, an erect free-floating herbaceous plant, spread throughout the world. In the absence of its original suite of natural enemies, and usually in nutrient-enriched waters, it quickly becomes invasive, and is now the most important aquatic weed worldwide[9,10] particularly in tropical Africa[11], India[12] and China[13], causing significant environmental, economic and social problems, particularly for communities reliant on water bodies for sustenance and survival.

Figure 1: *Eichhornia crassipes*

Pistia stratiotes L.

Pistia is a monotypic genus in the subfamily Aroideae.[14] *Pistia stratiotes*, also known as Jalkumbhi, is an free-floating stoloniferous, small aquatic perennial herb belonging to the aroid family (Araceae) 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.

Figure 2: *Pistia stratiotes* Free Floating Leaves form a Rosette

Economic Significance

An important part of natural products from plants, biomolecules and secondary metabolites usually exhibits some kind of biological activities. They are widely used in the human therapy, veterinary, agriculture, scientific research and in countless other areas.[15] The usefulness of plant materials medicinally is due to the presence of bioactive constituents such as alkaloids, tannins, flavonoids and phenolic compounds.[16] The presence of wide range of phytochemical constituent indicates that the plant could be used in a multitude of ways which may be beneficiary to the population.[17] Aquatic plants have economic and environmental uses, depending on the natural characteristics.[16] Originally from South America, *Eichhornia crassipes* (Mart.) Solms, a free-floating vascular plant, is one of the world's most pervasive aquatic plants. This plant is known to cause major ecological and socioeconomic changes.[18] The uses of plant-derived products as disease control agents have been studied, since they tend to have low toxicity to mammals, less environmental effects and wide public acceptance.[19] In Chhattisgarh, *E. crassipes* is being used as styptic. The fresh juice of this weed is used to treat fresh wounds as the tribes believe that it stops further spread of infection. Rice farmers consider this as a best first aid remedy for minor injuries. Along with vinegar, it is being used in treatment of septic wounds.[20] Back in folklore medicine, *E.crassipes* has been used to ease swelling, burning, haemorrhage, and goiters. In the animal kingdom, it has been used as a tonic for the skin of horses, for irritation and inflammation. Due to lack of modern medical facilities in remote and forest areas, tribal people who have the traditional knowledge, use indigenous plants in treating various ailments. This indigenous art of healing has to be transformed to an exact science.[21]

Phytochemicals and Secondary Metabolite

The preliminary phytochemical tests result indicates the presence of alkaloids, flavonoids, phenols, sterols, terpenoids, anthoquinones and protein and the absence of quinines, anthocyanin, saponin, carbohydrates and tannins.

Alkaloids play some metabolic role and control development in living system. They are also involved in protective function in animals and are used as medicine especially the steroidal alkaloids. Tannins are known to inhibit pathogenic fungi. Flavonoids are known to inhibit the initiation, promotion and progression of tumours.[22] The flavonoids and phenolic compounds in plants have been reported to exert multiple biological effects including antioxidant, free radical scavenging abilities, anti-inflammatory, anticarcinogenic etc.[23] Anthraquinones are considered to be one of the most active agents in metastatic breast cancer. The antimicrobial activity of the extracts could be explained by the presence of tannins. The mechanism of action of tannins is based on their ability to bind proteins thereby inhibiting cell protein synthesis.[24] Triterpenoids are a large class of natural isoprenoids present in higher plants, which exhibit a wide range of biological activities. Steroids (anabolic steroids) have been observed to promote nitrogen retention in osteoporosis and in animals with wasting illness. They reported the presence of alkaloids, flavonoids, sterols, terpenoids, anthroquinone, proteins, phenols and anthocyanins in ethanol fractionate of dry water hyacinth, in this study it was also found that fresh plant also contains metabolites as in dry plant except anthocyanins.[17] They demonstrated the presence of alkaloid, flavonoids, steroid, tannins, phenolic contents, quinone and anthraquinone in aqueous extract of dry *Eichhornia crassipes.*[22] They reported the presence of alkaloid, phenol, steroid, tannin and saponin in methanol extract of dry *Eichhornia crassipes* where as reported the absence of flavonoids.[15] They revealed the presence of saponin, glycoside and anthraquinone but absence of alkaloid in chloroform extract of dry water hyacinth[25] and presence of flavonoids in this plant.[26] They revealed the presence of phenol and tannin-like compounds in aqueous extract of fresh water hyacinth. The presence of high phenol content was due to the presence of specialized phenol cells. Tannin-like compounds were found to be released from the plant detritus and decayed materials after cutting or herbicide application. The antimicrobial studies show the good antibacterial potential of the ethanol extracts of water hyacinth. The results of phytochemical screening indicate that the plant extracts contains alkaloid and flavonoids. The antimicrobial activity of the extracts might be attributed to the presence of the foresaid secondary metabolites in the extracts.[27]

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.[28]

Phytoremediation

Eichhornia crassipes is a relatively cheap and environmentally friendly tool for the clarification of contaminated water because of its ability to absorb heavy metals (common pollutants) and its ability to grow rapidly.[29,30]

A comprehensive study on the arsenic removal from water by *E. crassipes* was performed and the results showed that it had a removal rate of 600 mg arsenic ha^{-1} d^{-1} under field condition and a removal recovery of 18% under laboratory conditions.[31] The removal efficiency of water hyacinth was higher due to its high biomass production and favorable climatic conditions. They compared arsenic removal efficiency of *E. crassipes*, *L. minor* and *S. polyrhiza* from tropical opencast coalmine effluent and observed that *E. crassipes* had the highest removal efficiency (80%) compared to other aquatic macrophytes over a 25 d course.[32] This was supposed to be due to faster growth rate,[29,33] greater biomass production, and higher uptake ability of arsenic. Water hyacinth represents a reliable alternative for arsenic bioremediation in aquatic system even though the plant may cause severe water management problems because of its huge vegetative reproduction and high growth rate.[34] So, the use of water hyacinth in phytoremediation technology should be considered carefully.

P. stratiotes mats degrade water quality by blocking the air–water interface, reducing oxygen levels in the water, and thus threatening aquatic life, it has been tested for metal remediation,[35,36] metal detoxification[37] and treatment of urban sewage.[38] Arsenic uptake by *P. stratiotes* has not been studied extensively. A field study reported that the average arsenic enrichment (bioaccumulation) factor of *P. stratiotes* was 8632 in roots and 2342 in leaf. It appears that arsenic translocation in *P. stratiotes* was slow and most of the arsenic was strongly adsorbed onto root surfaces from solution. This agrees with the earlier findings that arsenic compounds are less readily translocated through the root system of aquatic plants.[39]

Allelopathic Compounds

Several scientific studies indicate that water hyacinth, water lettuce, and hydrilla all emit allelopathic compounds that restrict growth of algal and/or plant competitors. In the case of water hyacinth, lab experiments indicating that various compounds extracted from water hyacinth roots had algicidal properties on *Chlorella* sp., *Scendesmus obliquus*, and undifferentiated phytoplankton that were comparable in activity to copper sulfate – a commonly used commercial algicide.[40] Similarly, several allelopathic chemicals isolated from water lettuce that showed inhibitory effects on seventeen of nineteen algal cultures, with *Lyngbya kuetzingii* and *Chlorella saccharophila* showing no inhibition.[41]

Sewage Lagoons

Water hyacinth (*Eichhornia Crassipes*) has received great attention because of its obstinacy and high productivity especially when grown in domestic sewage lagoons.[42] Water hyacinth is also known to have a promising potential for the removal of toxic metals and other pollutants from aquatic environments[43] though the purification of sewage by water hyacinth has not yet been generally embraced in some parts of the world.[44] Meanwhile in other parts, majorly developed countries, water hyacinth has been used to remove nutrients or pollutants from wastewaters.[45,46,47,48,49,50,51] Water hyacinth is blamed for the reduction of biodiversity as well. If it is introduced into foreign aquatic ecosystems, it could cause severe water management problems because of its vegetative reproduction and high growth rate.[52,34] However, its enormous biomass production rate, its high tolerance to pollution, and its heavy metal and nutrient absorption capacities qualify it for use in wastewater treatment ponds.[53,54,55,56,57]

Water hyacinth *(Eichhornia crassipes Solms*), due to its fast growth and large biogas production[56] has potential to cleanup various wastewaters. Inorganic contaminants such as nitrate, ammonium and soluble phosphorus[58,59] heavy metals[29,30]can be removed efficiently by water hyacinth through uptake and accumulation. Previously the roots of water hyacinth plants and their roots were used for phytoremediation of ethion and biosorption of reactive dyes.[60]

Fertilizer

Water hyacinth can be converted into compost and used on the land with proper management and technology. Water hyacinth is a well-known cleaner of polluted water & different pollutants (like heavy metals) are deposited in its root. So roots are generally removed in case where water hyacinth is collected from polluted water. As a green manure it can be either ploughed into the ground or used as mulch. Water Hyacinth and Cow dung in 8:1 ratio has been shown to greatly increase the agricultural production by many folds. Only the leaves and stalk portion of the Water Hyacinth has to be used. Straw can be added as an extra source of Carbon. Mud plastering at the outside of the heap is essential in all models for restoring moisture and temperature during composting.

Vermi Composting

Fresh water hyacinth is mixed thoroughly with cow dung (25%). After partial decomposing for 40 days, the earthworms are introduced and again composting is done for the next 40 days.

The size of the heap: 5' X 5' X 5' (Approx.). A study was conducted in Tamil Nadu Agricultural University, Coimbatore to explore the possibility of conversion of water hyacinth into nutrient rich vermicompost. Among various treatments, vermicomposting with *E. eugeniae* along with enrichment was found to be superior, considering the total N, P, K, Ca and Mg content of the vermicompost. Enrichment with Azospirillum, phosphobacteria and rock phosphate significantly increased the total N, P and Ca content in the vermicompost. This kind of manure production can be done by any farmer with access to a small pond with Water Hyacinth. No investment or instruments is required, only labour and time.

Bio Plastics

Researchers at Manonmaniam Sundaranar University in Tirunelveli, Tamil Nadu, have found that water hyacinth-derived sugar molecules like lignin, cellulose and hemicellulose can be converted into polyhydroxybutyrate (PHB), a polymer that is a raw material for making biodegradable plastic. Plastics developed using PHB are compostable. Also, making PHB from natural resources can reduce cost and harmful gas emissions. To make PHB, researchers dried and crushed water hyacinth into a fine powder and subjected it to acid and enzyme treatment in the presence of water. The end product was used to grow *Cupriavidus necator*, a bacterium known to produce PHB, in the presence of organic and inorganic nitrogen sources. As the bacteria grew, PHB was found to accumulate inside them. Researchers ruptured the bacterial cells using an alkaline solution and extracted the PHB. Maximum PHB, 4.3 grams per litre, was obtained from the bacteria cultured using the products of enzymatic breakdown of water hyacinth powder. The quality of PHB derived from hyacinth will be similar to PHB from other sources. The advantage with using water hyacinth as raw material is that it is available free of cost throughout the year. More research is needed to commercialise the Bioplastics production from the Water Hyacinth.[61]

Biogas

E. crassipes include biogas production[62] use as animal fodder, fertilizer, in the manufacture of paper and furniture, in waste water treatment, and in water quality management.[63]

There is world-wide interest in biogas production, and research is undertaken and equipment manufactured in many tropical countries. Biogas is a combustible mixture of methane (50 - 70%) and carbon dioxide, with traces of hydrogen sulphide and water. This gaseous mixture is formed naturally. It is produced spontaneously in the rumens of cows, which each day produce about 200 litres of methane gas. It is also given off from the bottom of some marshes and lakes, and from rubbish dumps. It is formed by the process of anaerobic digestion, in which micro-organisms break down organic material in the absence of oxygen. This process has been used to treat sewage waste for over 100 years. The energy crises of the 1970s stimulated the construction of digesters, particularly in India and China, where there was already a committed interest in the process.[64,65] Since the late 80s, a great interest has developed in many countries, partly because of the fuel wood crisis and partly because of the improved technology available. It has been estimated that each year one hectare can yield about 100 tonnes of dry water hyacinth, that this, in turn, can produce 30,000 m^3 of gas, and that this could satisfy the cooking needs of 40 or 50 rural families.

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.[66]

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.[67]

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.[68]

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 1^{-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.[32]

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.[69]

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.[70]

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.[71]

CONCLUSION

Bioresources are the different forms of living organisms those have potential to generate wealth and improved the lives. Therefore, exploration, conservation and preservation of bioresources are the centre of attention around the world.

Pistia stratiotes (Family: Araceae) is commonly used in Ayurvedic medicine which possesses diuretic, antidiabetic, antidermatophytic, antifungal, and antimicrobial properties. This confirms the reproducibility and potential therapeutic effects, along with some "leads" with possible isolation of active biomoieties and their mechanism of action.

Eichhornia crassipes is world's worst aquatic plant that causes a serious hindrance to nation's developmental activities. The present investigation was planned to explore the potential positive attributes which outweigh the negative ones. Qualitative analysis revealed the presence of important components including tannins, phoblatannin, steroid, terpenoid, alkaloid, flavonoid, phenolic contents, quinones, antraquinones and cardiac glycosides.

Hence, an alternative approach for the development of novel drugs is represented by the wide empirical screening of chemical entities for antimicrobial activity. The purpose of finding the chemicals in *E. crassipes* and *P. stratiotes* plants worthwhile as the output is "Best out of waste".

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