Review Article
MULTIFACETED POTENTIAL OF EICHHORNIA CRASSIPES (WATER HYACINTH) LADENED WITH NUMEROUS VALUE AIDED AND THERAPEUTIC PROPERTIES

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Abstract
Being an aquatic weed which is growing dense and widespread across many lakes and water bodies, it is of paramount importance to utilize Eichhornia crassipes (commonly known as water hyacinth) for the benefit of the mankind, especially for its value added and medical properties, such as bio-fuel, biogas, bioremediation and therapeutics. Many of the bird sanctuaries and water-bodies have been drastically invaded by this aquatic weed which is really affecting ecological niche and bird migrations. Several researchers have successfully demonstrated the use of water hyacinth in the bio-remediation and as a potential source of renewable energy. Different heavy and toxic metals showing biomagnifications and therefore creating health hazards, could be remediated by using water hyacinth. The process of decontaminating agro-industrial waste polluted with heavy metals, organic and inorganic pollutants could possibly be done using water hyacinth. Current review focuses towards the efforts to utilize this weed for different value added and therapeutic properties. Furthermore the article emphasizes upon the need to gain more insight into the mechanism with concrete randomized controlled studies to find out the effects of this weed on human health and a sustainable solution to exploit and manage this invasive otherwise harmful weed into a beneficial entity for the mankind.

Keywords: Water hyacinth; value aided properties; bioremediation; bio-energy; bio-fuel; biogas; therapeutic

Introduction
Water hyacinth is known to have its origin from Brazil mainly in the rainforests of Amazon river along with some other regions of South America as well. One of the most invasive aquatic plant species worldwide, the water hyacinth (Eichhornia crassipes) is a perennial macrophyte monocot which belongs to Pontederiaceae family comprising of thick rounded green leaves, and lavender blue flowers while having dark purple to black roots with rhizomes and stolons (Patel, 2012; Gettys et al., 2014). Nutrient rich water-bodies are the right spots for its multiplication with a doubling time of 1-3 weeks (Gopal, 1987a, Ndimele et al., 2011). In terms of chemical composition, water hyacinth is enriched in nitrogen levels (3.2% of dry material) with a carbon to nitrogen ratio of 15. Given to their strong ability to uptake considerable amounts of nutrients and other chemicals, the chemical composition is likely to vary depending upon the environment (Gunnarsson & Petersen, 2007).

Characteristic features, factors and regulation
The cultivation of this otherwise invasive weed has reached more than 50 tropical and subtropical countries in the world with wide-abundance in Southeast Asia, Africa, Europe and United States as well having a mean biomass production of more than 140 tons per hectare per year (Abdelhamid & Gabr, 1991; Waebret al., 2015; Lindsey & Hirt, 1999; Brundu et al., 2012; Bartodziej & Weymouth, 1995; Brendoncet al., 2003; Lu et al., 2007; Jimenez & Balandra, 2007; Toft et al., 2003, Chabot). Both tropical and temperate environments have been reported to be equally suitable for the growth of the aquatic weed. Optimal temperature for growth of this invasive weed is between 25 to 27.5 °C while a pH range between 6 to 8 is considered optimal. While another study reported the optimal temperature for growth between 28–30°C (Burton et al., 2010). However, this plant is quite sensitive to salinity with 0.6% or more being vulnerable to the plant growth(Mangas-Ramírez & Elías-Gutiérrez). Moreover, the plant is not able to grow in the water having temperature either below 10°C or above 30°C. Being euryhaline in nature, it could growth both in fresh and marine water, though stationary or slow-flowing fresh water is most suitable for the infestation and further growth(Ojeifo et al., 2000; Burton et al., 2010). Some studies also reported about its ability to sustain adverse climatic conditions, and its ability to survive in damp soils for months, making it more invasive as well (Burton et al., 2010). Water hyacinth seeds take about six months to germinate and remain viable for more than 15 years in the soil. In addition they have a remarkable capacity to regenerate rapidly even from stem fragments (Gunnarsson & Petersen, 2007; Ueki et al., 1976; Malik, 2007). A salinity level of more than 0.6% is lethal for the plant.

Ecological dysbiosis
Water hyacinth because of its ability to grow in diverse nutrient conditions and fastidious in nature, it has become the fastest growing free floating hydrophyte in the world (Gopal, 1987a; Gopal, 1987b). Nutrient abundance and availability are indispensable for its growth and propagation with nitrogen, phosphorus and potassium required in larger amounts (Burton et al., 2010; Xie et al., 2004). There has
been a direct correlation observed between the concentrations of nutrients with the rate of infestation of water hyacinth. This weed does have the capacity to store excess nutrients to be used further in later life stages (Heard & Winterton, 2000). There have been numerous ecological alterations in aquatic ecosystem, abiotic factors imbalance attributed to the hyper-invasion of this aquatic weed resulting in the formation of dense mats affecting water quality, reduced penetration of sunlight along with reduced availability of dissolved oxygen, leading to excessive evapo-transpiration rate and drying of water-bodies especially shallow lakes (Villamagna & Murphy, 2010; Gopal, 1987b). The negative consequences of such an ecological dysbiosis is quite vulnerable to the flora and fauna communities for e.g. because of the less penetration of the sunlight, the phytoplankton abundance tend to get decreased as a result of which the whole food chain comprising of aquatic invertebrates, fish and bird communities, is negatively affected (Gratwicke & Marshall, 2001; Villamagna & Murphy, 2010; Toft et al., 2003). Furthermore, the water hyacinth can easily outnumber the submersed native species because of its aggressive and invasive nature (Midgle et al., 2006).

Not only the native species which is affected by water hyacinth but even humans are impacted because of the ecological dysbiosis. Water-channels get blocked because of the deposition of the dense cell mass or mat formed by this weed resulting in disruption of the transportation, irrigation and hydropower generation (Honlah et al., 2019). Nitrites and phosphate enriched nutrients accumulated in the water-bodies as a result of runoff’s from rainwater from untreated wastewater, sewage and fertilized fields, have been known to enhance the growth of water hyacinth. Moreover, the construction of dams for hydropower, irrigation, water extraction and aquaculture are also known to reduce the flow of the river system, again providing ambient conditions for the water hyacinth colonies to grow (Hauser et al., 2014; Honlah et al., 2019). Fishing activity is also hindered resulting in huge economic losses as reported previously in literature (Calvert, 2002; Joffe & Cooke, 1997). Water hyacinth in the water-bodies also provides a rich platform and microhabitat for carriers/ vectors of various diseases. Female anopheline mosquitoes which are the carriers of Plasmodium species causing malaria, rear in abundance in such microhabitats, threatening human lives (Joffe & Cooke, 1997). Many snakes, hippos and crocodiles are likely to hide in such water-hyacinth infested places, again proving dangerous for humans (Gunnarsson & Petersen, 2007).

Broad-Spectrum Applications

Many economic benefits could be derived from water hyacinth such as to produce biofertilizers, biogas, biofuel, bioremediation of heavy metals from waste-water and other contaminants, fodder, briquettes, furniture, and handicrafts along with therapeutic effects (Jafari, 2010; Patel, 2012) [Fig. 1]. Dried water hyacinth have been found to be much more economical for the developing countries. Because of the presence of high crude protein content, water hyacinth has been proved to be a suitable fodder as a part of the diet for ruminants, pigs and ducks (ELDIN, 1992; Jafari, 2010; Joffe & Cooke, 1997; Tham, 2012).

a. Phytoremediation

The plant’s attributes certainly point towards this weed could be a hyperaccumulator mediating the process of removal of contaminants from the environment or wastewater, thus could be an attractive source as a low-cost, green, phytoremediation strategy (Jones et al., 2018; Sharma et al., 2016; Wolverton & McDonald, 1975). This cost-effective strategy holds promise in order to remove heavy metals, pesticides, hydrocarbons etc. from contaminated sites (Sharma et al., 2016). Scientific community have focused on this particular organism because of its unique features such as its invasive growth, increased biogas production, ability to grow in polluted diverse environments, scavenger of heavy metals and ability to accumulate metal ions like cadmium, nickel, mercury etc. from industrial effluents (Malik, 2007; Sharma et al., 2016). Water hyacinth has been extensively exploited for its capacity to absorb contaminants and nutrients; thus posing as a potential biological alternative for the improvement of wastewater quality and effluent quality as well (Ho & Wong, 1994; Cossu et al., 2001). Water hyacinth was reported to accumulate many trace elements including nickel, copper, chromium and cadmium in a hydroponic study (De Souza et al., 1999). Similarly leaves of the weed had been able to accumulate mercury as well indicating the possible association of water hyacinth in mercury remediation (Greenfield et al., 2007). Furthermore another study revealed its role in the removal of arsenic and better removal rate in comparison to duckweed (Alvarado et al., 2008).

Using appropriate water hyacinth based phytoremediation system, the ammoniacal nitrogen (AN) removal process was enhanced facilitating the design of an industrial scale phytoremediation system for the effluent treatment; hence paving the way for industry to reduce the AN level in their effluent discharge (Ting et al., 2018). Water hyacinth root system is quite complex, which were also shown to remediate arsenic from waste water (Shabana & Mohamed, 2005). More so a lanthanide metal, europium was also remediated through the water hyacinth roots system as determined through scanning electron microscopy with highest concentration of the metal reported on root hairs (Kelley et al., 1999). Also its dried roots and the ash and activated carbon derived from this weed were found to act as decontaminating agent (Schneider et al., 2001; Mahmood et al., 2010; Mahamadi, 2011). Moreover this could act as a biological monitoring agent for heavy metal pollution as well (Zaranyika et al., 1994). Many organic (e.g. phenol) and inorganic contaminants (nitrites, phosphates, choline, sulfur, silicates etc.) are also efficiently absorbed by this aquatic weed; though exact mechanism of action is still to be understood (Reddy, 1983; Ogunlade, 1992; Nora & Jesus, 1997; Zimmels et al., 2007). In addition, E. crassipes was reported to be having highest capacity for nitrogen and phosphorus extraction (Kiran et al., 1991).

Efficient uptake of ethion, a phosphorus pesticide, recalciitrant organic chemicals such as herbicides and pentachlorophenol were also observed for accumulation and bioremoval by this aquatic weed (Xia & Ma, 2006; Roy & Hänninen, 1994). The sorption of uranium, copper and many basic dyes by the water hyacinth roots were also reported previously (Shawky et al., 2005; Low et al., 1994). Even waste water from pulp and paper industry, tannery and textile industry could be decontaminated using water hyacinth roots (Jayaweera & Kasturiarachchi, 2004). There have been many positive beneficial effects recorded on the abundance of zooplanktons, macro-invertebrates and fish communities as...
well (Villamagna & Murphy, 2010). Infect different plant parts have been reported for the biosorption of various metals and pollutants in the past (Sharma et al., 2016). Keeping in view of the above facts, one might consider water hyacinth as an efficient and cost effective agent to hasten the process of decontaminating agro-industrial waste polluted with heavy metals, organic and inorganic pollutants.

b. Biofuel and Biogas Production

Keeping in view of the abundance of the weed in freshwater, marine, and aquatic ecosystems throughout the world, water hyacinth (Eichhornia crassipes) derived biodiesel (WHB) was proposed as a potential alternative energy source (Venu et al., 2019). Another study also successfully showed the ability of water hyacinth to produce biodiesel(Sagar & Kumari, 2013). Increased industrialization and urbanization have been detrimental to our non-renewable energy resources resulting in energy crisis globally. Therefore we need fuels to be generated from renewable resources which are readily available. Owing to wider distribution and higher cellulose and hemicellulose contents in the water hyacinth biomass, it has the potential for bioethanol production tackling the growing problem of pollution attributed to fossil fuel emissions (Deka et al., 2018).

Water hyacinth having low lignin content has been an attractive biomass source for the biofuel industry [Fig. 1]. Metal-contaminated water hyacinth was also shown to produce bio-ethanol in one of the studies reported earlier (Mahmood et al., 2010). Another study reported that the ethanol generating capacity of water hyacinth was quite comparable to that obtained from agriculture waste (Mishima et al., 2008). Genetic engineering technology has further enhanced the production of ethanol from hemicellulose content present in this invasive weed which is fermented to oligosaccharides (Dien et al., 2003; Mishima et al., 2008). There have been few biological methods adopted to delignify the water hyacinth biomass for the large scale production of ethanol (Sari et al., 2011). Majority of the studies have indicated that biofuel production from water hyacinth holds promise in terms of cost effectiveness, economic and environment friendly approach.

Similarly biogas which is primarily composed of methane and CO₂, the water hyacinth biomass could be an attractive source for biogas production because of its aggressive and invasive growth. Moreover the higher cellulose and hemicellulase contents along with larger C/N ratio makes it even more destined to produce biogas(Chanakya et al., 1993). Many studies reported that on an average a tonne of semi dried water hyacinth biomass could produce about 4000 Liter of biogas with about 64% methanolic content (Gopal, 1987b). However a mixture of water hyacinth and animal waste (cow dung etc.) could yield even higher production of Biogas (Jafari, 2010; El-Shinnawi et al., 1989b; El-Shinnawi et al., 1989a). While the sludge or slurry left behind after biogas production is transported to be used as a liquid fertilizer. Similarly in vermicomposting, since water hyacinth loses the ability to reproduce vegetatively after passing through the earthworm gut but the presence of enzymes and hormones in the vermicast are known to stimulate plant growth and flowering as well (Gajalakshmi & Abbasi, 2002; Ansari & Ismail, 2012; Ramasamy & Abbasi, 1999). Pig dung blended and mixed with water hyacinth (1:3 ratio), were found to enhance the percent composition of methane in biogas (Adegunloye et al., 2013). A mixture of water chestnut, water hyacinth and cow dung (in 1:1:2 ratio), after anaerobic digestion could produce biogas at an average of 0.326 L per day (Sudhakar et al., 2013). Another study reported the biomethanation of fresh water hyacinth with varying amounts of water could produce even higher levels of biogas (Patil et al., 2011).

The need is to make the biogas production cheaper, cost effective and less labour intensive. Moreover weed harvesting for the biomass and further for biogas production not only keep the weed under check for its growth and invasiveness but simultaneously fulfilling the energy availability and environmental sustainability as well.

Figure 1

Fig. 1 : Broad spectrum applications of Eichhornia crassipes

![Figure 1](image-url)
c. Therapeutic Applications

It seems evident that antimicrobial, antifungal and antibacterial properties are associated with water hyacinth and many skin care products are known to contain hyacinth as well, good enough to treat many skin disorders [Fig. 1]. Water hyacinth was reported to have significant levels of vitamin C (ascorbate) as determined through cyclic voltammetry having underlying therapeutic applications in skin disorders and goiter as well (Ogunlesi et al., 2010). Moreover water hyacinth in shampoos has been used to increase the fragrance to that of a fresh flower. Water hyacinth along with table salt and Piper longum has long been used for the treatment of goiter (Oudhia, 1999). Water hyacinth is now confirmed to be a great source of natural antioxidants with freeze dried leaves to be the richest source (Bodo et al., 2004b; Bodo et al., 2004a; Lalitha & Jayanthi, 2014). Moreover water hyacinth extracts have shown encouraging anti-aging effects as determined through DNA damage inhibition and DPPH radical scavenging assays. There was a pronounced increase in the DNA damage inhibition and DPPH radical scavenging ability with the increase in concentration of the ethyl acetate extracts of Water Hyacinth; thus having promising cosmeceutical industry prospects (Lalitha & Jayanthi, 2014). In Chinese traditional medicines, *Eichhornia* beans have been used for healthy spleen functioning. Similarly in Philippines, *Eichhornia* juice with lemon juice is traditionally used as an anti-inflammatory topical agent. Stir-fried hyacinth beans have been traditionally in use to treat digestive disorders, flatulence, diarrhea, intestinal worms and regulating cholesterol levels. Similarly stems of water hyacinth are traditionally used to treat cholera. Leaf extract of water hyacinth with rice flour and turmeric have been used for eczema. Also as traditional medicines, water hyacinth has been used to treat gonorrhea with the help of infusions prepared with the leaves of hyacinth plant. Some tribes in Kenya, use this herb beans to promote lactation while its flowers could help women who suffer from irregular periods. Even water hyacinth is known to contain some therapeutic compounds bearing anti-cancer properties (Aboul-Enein et al., 2014). Therefore water hyacinth seems to have many broad spectrum properties of therapeutic significance.

Management of Water Hyacinth

There have been several adopted methods to control and manage the water hyacinth and to contain its spread (Sharma et al., 2016). But still no effective control strategy has been developed till date. The management of *Eichhornia* still depends on efforts that focus on reducing the ecological and socio economic damage caused by it. In terms of physical methods, using machinery and human labor is widely followed because of its efficiency but due to cost issues, it may incur huge economic losses to the concerned farmer or individual (Alimi & Akinmyiju, 1991). However use of chemicals such as Glyphosate/ Diquate or 2,4D has been less expensive in order to eradicate water hyacinth but again many risks engendered to the populations and to the ecosystem, make them less favored for the said use(Charudattan et al., 1996). Integrated management of this weed was also carried out using Glyphosate at a low concentration along with A. alternate (Ray & Hill, 2012). Similarly in another integrated weed management approach, microbial herbicide, natural populations of arthropods and chemical herbicides were used together (Charudattan, 1986).

Though the initial focus was to control water hyacinth by eradication but due to the limitations of this approach, researchers tend to put more efforts on reducing the density of water hyacinth to levels that could minimize the economic as well as ecological impacts.

Biological control has been a good alternative as one could manage and restrict this weed by using some natural predators. Many weevil species such as *Neochetina eichhorniae, N. bruchi* or the moth species such as *Sameodes abigullatis* or the fungal pathogen, *Alternaria eichhornia* have been successfully tried in the past with positive outcomes (Shabana & Mohamed, 2005; Coetzee et al., 2009). However, these natural predators may also hit non-target species as well, warranting their use because of the associated risks (Simberloff & Von Holle, 1999). Moreover their effects could be site-specific as well as has been seen in a study where two weevil species could effectively reduce water hyacinth population in one specific area but failed in the other (Schardt, 1986).

Challenges

There are many opportunities and challenges which the water hyacinth presents before the scientific community beyond the bio control (Sharma et al., 2016). Lack of technological skills, skilled manpower, lower investments in machinery especially in developing countries and poor rural areas where this weed is largely spread and prevalent, have been the foremost challenges for exploiting this weed for good human use such as for biogas production, furniture, handicrafts and briquettes (Thomas & Eden, 1990; Gunnarsson & Petersen, 2007). Moreover we need sufficient market outlets as well in order to derive maximal benefits which is again a challenge for the poor countries (Patel, 2012). Further more intensive labor is required for transportation of the bio-compost which makes it unrealistic to be produced at a bulk scale especially for the low-income countries (Gunnarsson & Petersen, 2007). Extensive efforts with large cohorts of samples and randomized controlled studies and trials are needed to find out the effects of this weed on human health and a sustainable solution to exploit this invasive otherwise harmful weed into a beneficial entity for human applications.

Conclusions

This invasive weed is a threat to the biodiversity resulting in huge economic losses and a concern to the health of human beings as well (Degaga). However, there have been numerous value aided properties attributed to Water hyacinth as it is used for not only in the water purification process, biogas and biofuel production but also for the efficient removal of heavy metal contaminants of environmental concern from waste water in a cost effective manner. Many critical factors including temperature, pH, adsorbent dose etc. play a significant role in the biosorption capacities but still a lot to be done in this field especially to put forth bulk scale procedures in order to derive maximum benefits out of this invasive weed.

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Conflict Of Interest

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References


Degaga, A.H. Water Hyacinth (Eichhornia crassipes) Biology and its Impacts on Ecosystem, Biodiversity, Economy and Human Well-being.


