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A review on potential uses of invasive aquatic weed; water hyacinth

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ABSTRACT

By invading freshwater habitats, aquatic invasive species pose a danger to socioeconomic and ecological systems. *Eichhornia crassipes* (Mart.) Solms (water hyacinth) is one of the most recognized noxious floating aquatic weeds. It has invaded almost all aquatic systems over the world. Under optimum condition, water hyacinth grows in massive quantities causing detrimental effects on both the environment and human health. The present review gives a summary of water hyacinths distribution, problems and different management strategies adopted to control its spread in the aquatic environment. Also, the review summarizes different aspects of beneficial uses of water hyacinth. The review discusses the plant uses as a source of feed for animals and fish. Also, it gives a brief about the plant uses for biofuels production. The use of the living plant as well as its biomass for bioremediation and bioaccumulation of harmful pollutants and metals for water treatment has been also pointed out in the present work. Last but not least the present review highlights some novel applications using water hyacinths such as the production of nanomaterials, hydrogels, building materials and other miscellaneous applications.

INTRODUCTION

Eichhornia crassipes (Mart.) Solms (water hyacinth) (Fig.1) is a free-floating aquatic weed originating from South America. Since the nineteens, it began to be considered invasive in Africa and Asia **(Dersseh *et al.*, 2019).** Water hyacinth grows best in water with a high level of nitrogen, phosphorus and potassium at water temperatures between 28°C and 30°C. Under optimum conditions, the growth rate in the freshwater environment of water hyacinth is exceptionally high **(Dölle *et al.*, 2021).** Under favorable conditions, a water hyacinth mat can grow up to 60 m/month and its seed can be sustained on the bottom of the invaded water body and can last for up to 20 years **(Auchterlonie *et al.*, 2021).**

Water hyacinth can cover lakes and wetlands, outcompete indigenous aquatic species, reduce levels of oxygen to fish, and establish a perfect habitat for mosquitoes that carry diseases. Large water hyacinth infestations can obstruct transport through the rivers, hinder fishing and clog dams **(Stohlgren *et al.*, 2013).** Blockages in canals and rivers can lead to dangerous floods. Increased water hyacinth evapotranspiration, on the other hand, may have serious repercussions for places where there is still insufficient water. The depletion of biodiversity is also another problem associated with water hyacinth **(Abhed, 2020).**

Figure 1: Classification of Water hyacinth

1.Management of water hyacinth

Four methods have been proposed for controlling and managing the growth and spread of water hyacinth, these are mechanical, chemical, environmental and biological methods (Figure 2) **(Joshi *et al.*, 2019).**

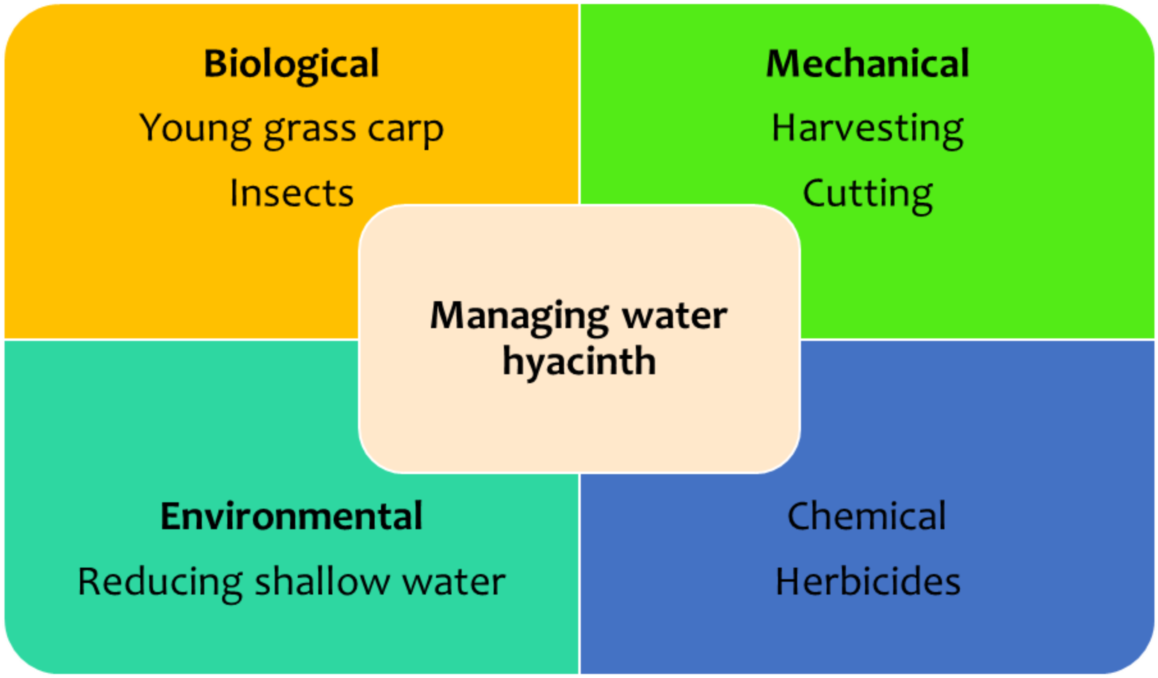

Fig. 2 Methods for water hyacinth control

The management protocols for controlling the growth of water hyacinth are proceeded by biological , mechanical , environmental and chemical methods. Each of these management methods has its advantages and disadvantages. In the chemical method, the plants are sprayed in situ with herbicides which require the equipment and expertise needed and can adversely affect the purity of water and non-targeted animals or plants **(Auchterlonie *et al.*, 2021).** The mechanical harvest or shredding water hyacinth shoots and living them to die is a popular alternative to the use of herbicides, but the harvest is relatively expensive as equipment is needed and also it is time-consuming **(Greenfield *et al.*, 2007).** Environmental control methods include reducing the amount of shallow water and limiting the sunlight so that plants cannot make adequate food but this method is not effective when the plants have started to grow closer to the water surface **(Joshi *et al.*, 2019).** On the other hand, the biological control methods involve introducing biological control agents and is one of the best methods for reducing water hyacinth populations and eight species of biological control agents have been released throughout the world **(Coetzee and Hill, 2012).**

2.Beneficial uses of water hyacinth

Even though water hyacinth is causing major environmental and economic problems, but the weed has been exploited for several beneficial uses. The uses of water hyacinth include fertilizers, feed, biofuel and phytoremdiation, water treatment, etc. (Figure3).

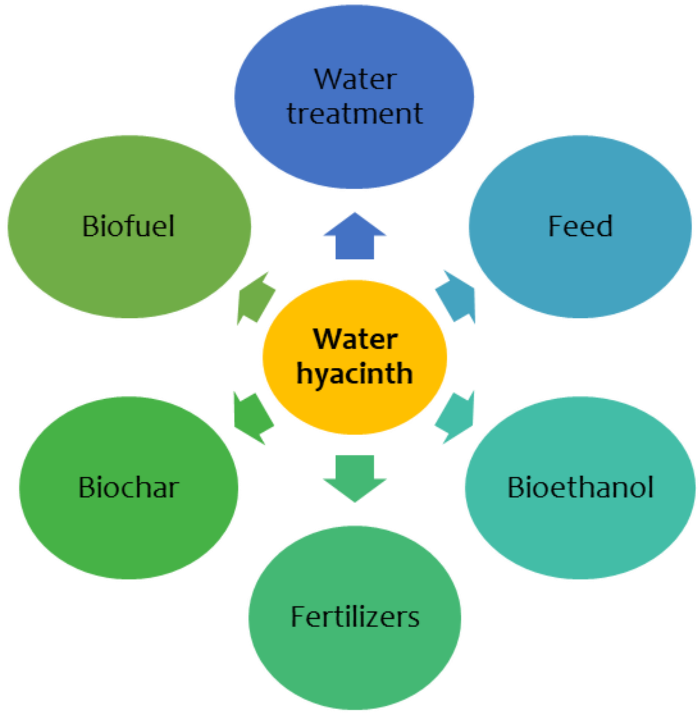

Fig. 3. Beneficial uses of water hyacinth

3.Water hyacinth as feed

Water hyacinth leaf protein concentrate was shown to contain valuable amounts of nutrients including 56.38 % crude protein, 33% carbohydrates and seventeen amino acids **(Adeyemi and Osubor, 2016).** Freshwater hyacinth has a crude protein content of 2.38 %, a crude fat content of 0.27 %, crude fiber content of 0.91 %, and a nitrogen-free extract content of 3.7 %. However, since water hyacinth dry matter is high in nutrients and contains 10–20 % crude protein, it can be used to supplement protein feed and roughage **(Su *et al.*, 2018).**

The inclusion of water hyacinth leaves extract in the diet of rainbow trout showed positive effects on its immune and antioxidant parameters and increased trout's survival rate **(Rufchaei *et al.*, 2020). Indulekha *et al.*, (2019)** investigated the conversion of water hyacinth to silage for its use as animal feed and enhanced its nutritional quality by adding molasses and cassava. The effect of including ensiled water hyacinth in cattle diets showed that it considerably improved crude protein intake and digestibility of nutrients **(Tham and Udén, 2013).** The use of water hyacinth leaves as a substitution for concentrate mixture up to 75% resulted in optimum growth of Washera sheep **(Mekuriaw *et al.*, 2018).** Based on its nutritive value, water hyacinth was used as feed for pigs in Nigeria and showed positive results on feed consumption, weight gain and cost-effectiveness **(Mekuriaw *et al.*, 2018). Sunday, (2010)** studied feed intake, rate of gain and feed efficiency of growing goats fed a basal diet composed of water hyacinth with cowpea pod and groundnut stubbles and concluded that including dried water hyacinth in the diet of goats had beneficial effects. The utilization of water hyacinth plant in livestock feed to reduce the feed shortage in Sri Lanka **(Wimalarathne and Perera, 2019).** Water hyacinth was incorporated into broilers' diet with no adverse effect on their production performance **(Dumaup and Ampode, 2020).** Dried water hyacinth leaves and stems were used as feed for rabbits in concentrate feed mixture without negative effect on rabbits' growth, feed conversion, economic efficiency and digestibility **(Hassan *et al.*, 2015).** Water hyacinth leaves were efficiently used to replace 20% of the high cost protein source from fishmeal and soybean meals in the diet of tilapia **(Fouzi and Deepani, 2018).**

4.Water hyacinth for Biofuel production

Because hydrocarbon fuels decrease every year, green energy is essential to fulfilling rural and urban energy needs **(Bote *et al.*, 2020)**. Water hyacinth can be explored for the development of biofuels due to its high hemicellulose and cellulose content. As its productivity is high, it can be used as a feed supply for biofuels production. Water hyacinth offers many benefits as it can flourish on the water without competing for grain and vegetables **(Sindhu *et al.*, 2017).**

An anaerobic digestion process was developed to produce biogas (methane 45.18%) and electricity (395.5 W) from water hyacinth and also the remaining was successfully used as raw fuel for briquette production **(Bote *et al.*, 2020).** Novel biodiesel was produced from water hyacinth and tested in a compression ignition engine. The biodiesel from water hyacinth showed better diffusion combustion and lower emission of harmful gasses as compared to normal diesel **(Alagu *et al.*, 2019).** Bio-oil was produced by slow pyrolysis of water hyacinth biomass with a 24.6 weight percentage maximum yield **(Biswas *et al.*, 2017).** The biomass of water hyacinth was aerobically digested for the generation of renewable bio-methane **(Ali and Sun, 2019).**

Water hyacinth was treated with microwave-assisted dilute H_2SO_4 for bio-hydrogen production with a yield accounting for 75.2% of the theoretical hydrogen yield **(Cheng *et al.*, 2013).** Water hyacinth stems were hydrolyzed and used as the substrate for bio-hydrogen production with a maximum production of 127. 6 mmol H_2/L at optimum conditions **(Pattra and Sittijunda, 2015).** Water hyacinth was converted into a value-added fuel via hydrothermal carbonization **(Zhang *et al.*, 2020).**

5.Water hyacinth for water treatment

The issue of water shortage is growing worldwide and the treatment and reuse of wastewater can be considered a viable alternative for water management **(Mostafa *et al.*, 2019)**. Heavy metals are released into the environment through different activities **(Abdel-Ghani *et al.*, 2013)** and are causing critical damages because of their persistence and accumulation **(Abdel-Ghani *et al.*, 2008),** thus their removal is a must.

In this respect, water hyacinth is considered a good candidate for remediating contaminated sites owing to its ability to absorb heavy metals from water. Water hyacinth succeeded in uptake and translocate Ag, Cd, Cu, Pb, Sb, Sn and Zn from an e-waste recycling site proving its capacity for heavy metals removal from water **(Du *et al.*,**

2020). Remediation of zinc and chromium ions was achieved by the use of dried biomass of water hyacinth from electroplating wastewater industries. The potential of powdered components of water hyacinth (leaves, petioles and root). Maximum removal of zinc was achieved by the dry roots as 98.9% and removal of maximum removal of chromium was shown to be 96.4% and was obtained by the dry stem **(Shen *et al.*, 2018).**

The removal of heavy metals copper and cadmium from the water was achieved by water hyacinth roots and the amine and oxygen-containing groups were identified as the main binding sites of water hyacinth that accounted for metal sorption via chelation or coordination **(Zheng *et al.*, 2016).** The powder of water hyacinth shoots was capable of removing 98.83% and 99.59% of copper and chromium, respectively from a tannery effluent **(Sarkar *et al.*, 2017).** Biochar was prepared from water hyacinth biomass and under optimum conditions, the biochar adsorption capacity for lead ions reached 251.39 mg/g **(Zhou *et al.*, 2020).** Water hyacinth was employed to synthesize a novel magnetic hybrid suitable for the removal of copper, zinc, nickel, cobalt, and ibuprofen from aqueous media **(Lima *et al.*, 2020).**

The utilization of water hyacinth biochar for adsorption of trivalent chromium ion from tannery effluents was investigated and the biochar was able to remove 99% chromium in 15 minutes **(Hashem *et al.*, 2020).** Also, chemically modified dried water hyacinth root were capable of adsorbing chromium from synthetic solutions with an efficiency of 95.43% **(Kumar and Chauhan, 2019).**

The high level of absorption of nutrients along with absorbing organic substances such as formaldehyde, phenol, oxalic, acetic and formic acid the contaminant resistance and the big output of biomass make water hyacinth an appropriate candidate for wastewater treatment **(Abbas *et al.*, 2019).**

Water hyacinth was used efficiently in treating domestic wastewater and reducing the amounts of chemical oxygen demand, phosphate, nitrate, ammonical nitrogen (NH_3), total organic carbon **(Rezania *et al.*, 2016).** Nutrients removal on a large scale was achieved using water hyacinth in in China **(Wang *et al.*, 2012).** Also, Water hyacinth effectively removed excess nutrients from polluted rural rivers with the highest removal efficiency for total nitrogen (89.4%) and ammonia (99.0%) **(Lu *et al.*, 2018).** The feasibility of water hyacinth for the treatment of formaldehyde in wastewater was also proven and the growth of water hyacinth was effectively controlled **(Gong *et al.*, 2018).**

6.Miscellaneous uses of water hyacinth

Many research works have reported different important uses of water hyacinth. For example, water hyacinth was investigated as a superplasticizer in concrete production **(Alagu *et al.*, 2019)** and thermal insulating material for buildings **(Philip and Rakendu, 2020).** Porous water hyacinth-derived carbon was successfully employed in supercapacitors electrodes **(Zheng *et al.*, 2017).** Water hyacinth was also used to produce a cellulose-based polymer hydrogel with high water retention properties that are excellent for application in agriculture **(Rop *et al.*, 2019).** A fluorescent nitrogen-doped carbon dots (N-CDs) was prepared from water hyacinth for tumors detection **(Paul and Kurian, 2020).**

Metal nanoparticles are widely used in many different biomedical applications and their synthesis using plant extracts is nowadays highly investigated **(Rashad *et al.*, 2019).** Water hyacinth stem cellulose was used to extract high-quality cellulose nanoparticles by successive thermochemical and alkaline-peroxide treatments **(Juárez-Luna *et al.*, 2019).** Silver nanoparticles were synthesized using water hyacinth plant leaves **(Oluwafemi *et al.*, 2019).** Also, an eco-friendly synthesis of platinum nanoparticles (Pt-NPs) using aqueous extracts from water hyacinth plant as efficient reducing and stabilizing agents **(John Leo and Oluwafemi, 2017).** The synthesis of silver nanoparticles (Ag-NPs) using cellulose extracted from water hyacinth was also achieved **(Mochochoko *et al.*, 2013).**

CONCLUSION

To conclude, water hyacinth instead of being regarded as an invasive noxious weed it could be regarded as a source and starting material for many beneficial uses. Different applications of water hyacinth have been addressed in this study. Weed biomass can be used for bioremediation and bioadsorption of different pollutants, as well as biogas and biofuel processing, composting and animal and fish feed. Thus, large-scale use of this noxious weed for weed control can be an appealing and productive approach that can replace the relatively unsuccessful traditional weed management methods.

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