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Occurrence, Diversity and Potential of Fungal Pathogens Associated with Water Hyacinth (Eichhornia crassipes [Mart.] Solms) for Sustainable Biological Management in Ethiopia: A Review

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Abstract

Ethiopia is blessed in biodiversity and is one of the twelve Vavilovian centers of origin. However, the country's biodiversity is threatened by more than 35 invasive alien species. Of the most destructive invasive alien species which pose serious threat to the Ethiopian water body is water hyacinth (*Eichhornia crassipes* (Mart.) Solms. The current review is aimed to provide basic insights towards the indigenous potential pathogenic fungi, their occurrence and severity of infection for effective water hyacinth management. The review result indicated that, about 25 fungal pathogens were identified causing infection to water hyacinth; collected from different infested areas of water bodies in Ethiopia. Among the fungal pathogens identified, *Alternaria alternata, Rhizoctonia* spp, *Alternaria tenuissima, Pythium ultimum, Fusarium oxysporum, Fusarium equiseti, and Neofisicoccum parvum* were highly pathogenic to water hyacinth. According to this review, the pathogenic fungi *Rhizoctonia spp and Fusarium* spp resulted in a complete death of water hyacinth with a mean diseases severity of 100% and 78.8% respectively. Similarly, *Pythium ultimum* and *Fusarium chlamydosporum* gave a satisfactory infection potential scoring severity of 5.67% and 5.33 respectively based on 1-6 severity scale measurement. Moreover, the fungal pathogen, *Alternaria alternata*, *Neofusicoccum parvum* and *Alternaria tenuissima* collected from rift valley, Ethiopia resulted in a severe reduction in water hyacinth height (48%-55%), root length (45%-50%), fresh (53%-67%) and dry weight (60%-72%) of water hyacinth showing their higher potential of this invasive weed management. It is also reviewed that, risk assessment of the fungal pathogen, *Alternaria alternate, Alternaria tenuissima* and *Alternaria* did not cause pathogenicity to 33 tested economically important crops of different categories like vegetables, field crops, cash crops and oil crops though it causes infection in water lettuce. In conclusion, based on host specificity test, severity of infection and the resultant reduction in vegetative growth of water hyacinth *Alternaria alternata, Alternaria tenuissima* and *Alternaria* spp. could be desirably the most promising bio-control fungal pathogen for effective management of water hyacinth in Ethiopia.

Keywords

Pathogenecity, Severity, Water hyacinth, Infection potential

Introduction

Certain aquatic weeds can negatively impact the environment and the livelihood of humans. Among the common aquatic weeds water hyacinth remains the most widely distributed and vicious aquatic weed [1]. It has become the world's most invasive, noxious aquatic weed due to its rapid spread, ecological adaptability, and negative impact it causes on the environment, economic development and human health [2]. The high growth rate of the plant and its ability to infest a wide range of freshwater habitats causes detrimental impacts on fisheries and related commercial activities, access to clean water, hydropower generation, irrigation, navigation along water courses and tourism. The impacts are most pronounced in developing countries, where human activities and livelihoods are closely linked with water

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systems [3]. In Ethiopia, water hyacinth was reported from Koka Lake and the Awash River about 60 years ago [4,5]. Since then, it has manifested itself on a large scale in many water bodies, including rivers, lakes, reservoirs, irrigation supplies and drainage systems [4,6,7].

Various methods were employed to control this invasive aquatic weed including manual, mechanical clearing and application of herbicides. However, the use of herbicides to control water hyacinth is only effective in the short term anywhere in the world [8,9]. Biological control of water hyacinth, which involves the use of natural enemies (i.e. insects and fungal pathogens) has been reported to be the most economical and sustainable method of control [5]. Fungal pathogens have gained acceptance as a practical, safe, environmentally friendly weed management method in agro-ecosystems worldwide [10] although their use has not been adopted in Ethiopia. Recommendations have been made to integrate fungal pathogens with insects to improve biological control of water hyacinth due to the insect feeding damage facilitating pathogenic infections of water hyacinth leaves [11].

Several fungal pathogens have been reported to attack water hyacinth worldwide [10,12]. Various strains in the genera *Acremonium, Alternaria, Cercospora*, and *Myrothecium* have been studied intensively as biocontrol agents and shown to be effective under experimental conditions [13,14]. One fungal species, *Cercospora piaropi*, originally described as *C. rodmanii* and patented by the University of Florida was developed into a bioherbicide for water hyacinth management. In Africa, several pathogenic fungi that attack water hyacinth offer great potential to be developed in to mycoherbicides [3,15,16]. However, In Ethiopia utilization of fungal pathogen for water hyacinth management is in its infancy stage although many potential fugi have been identified as effective.

Threats of Water Hyacinth

Reduction of water quality and biodiversity

The rapid reproductive nature of water hyacinth poses a great threat to biodiversity as the weed easily outcompete other species. Water hyacinth is challenging the ecological stability of freshwater water bodies [17], out-competing all other species growing in the vicinity, posing a threat to aquatic biodiversity [18]. Besides, Mengistu, et al. [19] reported that water hyacinth affects the composition of macrophytes, their abundance, and diversity in Lake Abaya, Ethiopia so that in extreme instances, the community of the macrophytes shrank into single flora. Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries. Moreover, Chukwuka and Uka [20,21] reported that species of rotifers, cladocerans, and copepods were significantly reduced in abundance due to the infestation of Awba Reservoir by water hyacinth in Nigeria. According to Tobias, et al. [22] water quality parameters such as dissolved oxygen, temperature, and turbidity were negatively impacted because of water hyacinth infestation. Besides, reduced concentrations of dissolved oxygen catalyze the discharge of phosphorus from the deposits present at the bottom of the water body which resulted speed up the rate of eutrophication, favoring and enhancing algal blooms [23].

Breeding ground for pests and vectors

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria [24]. Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed The abundance of water hyacinth on River Tano and Abby-Tano Lagoon in Ghana was reported to be a habitat for vectors of disease carrying organisms such as mosquitoes, thereby increasing the incidence of malaria infection in the communities around the two water bodies [25]. Water hyacinth has also been implicated in the transmission of schistosomiasis. Vectors of schistosomiasis snail species of the genus Biomphalaria and Bulinus have been reported to use the leaves of the weed as resting sites. Bulinus africanus and Biomphalaria sudanica were found to attach preferably to water hyacinth in Lake Victoria than to their native hippo grass [26]. Feikin, et al. [27] disclosed that there exists a very strong association between the number of cholera cases reported in the Nyanza Province of Kenya and the yearly water hyacinth coverage of Lake Victoria and suggested that water hyacinth might contribute to the outbreak of cholera thereby causing sporadic disease in the East African region. A marked difference was noticed in the Escherichia coli count in areas infested with water hyacinth and areas that are not around Lake Victoria [28] suggesting that the bacteria find the water hyacinth mats very suitable as a habitat. As the weed has the ability to easily spread, the disease associated with Escherichia colimay increase among the riparian communities.

Impact on fisheries

Fish is an essential nutrient in the human diet and is also present in the global aquatic product industry for consumers. Therefore we need to protect our aquatic environment against to pollution on various environmental and ecological effects. The aquatic ecosystems and living organisms suffer from environmental impact by emissions of volatile organic substances, and pollution of water by oil chemicals and many various hazardous agents [29]. The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species [20]. The weed has made fishing activity almost an impossible task in [30] by blockage of fish landing sites and destruction of fishing gear According to Cho and when water hyacinth infestation is present, access to fishing sites become difficult for riparian communities which rely solely on fishing as their main economic activity. The effects of the invasion on fishing and fish trading included a reduction in fish quality and catch, difficulty in using fishing gears, reduced profit, and increased cost of fishing. In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing

Table 1: Water hyacinth infestation level and area coverage in different water bodies of Ethiopia.

S/N	Water Bodies	Region located	Area coverage (ha)	References
1.	Wenji	Oromia	116.4	
2.	Abaya	SNNPS	5942.62	Dinknesh, et al., [54]
3.	Tana	Amhara	20,000-50,000	Wassie, et al., [55]
4.	Lume and Boa	Oromia	2319.48	Ebro, et al., [56]

Table 2: Intensity of different water hyacinth pathogenic fungi at different area in Ethiopia.

No.	Pathogenic fungi	Mean Incidence (%)	Mean disease Severity (%)	References
1.	*Rhizoctonia* spp	66.0	100	Admas, et al., [53]
2.	*Tricothecum roseium*	50.7	56.4	
3.	*Aspergillu flaves*	49.1	58.3	
4.	*Fusarium* spp	45.3	78.6	
5.	*Aalternaria alternate*	93.00	4.67	Tegene, et al., [52]
6.	*Pythium ultimum*	87.33	5.67	
7.	*Fusarium chlamydosporum*	86.67	5.33	
8.	*Fusarium equiseti*	86.67	4.67	
9.	*Ascochyta chartarum*	81.00	4.33	

Table 3: Intensity of different disease symptoms on water hyacinth in different Awash catchment water bodies in the Rift Valley during 2008.

No.	Water bodies	Number of sample areas surveyed	Mean disease incidence (%)	Diseases Severity (%)
1.	Aba Samuel Dam	44	21.93	16.00 (4.00)
2.	Afar Gidb	10	16.50	13.10 (4.00)
3.	Awash River	18	3.94	22.00 (4.00)
4.	Bate Gurmame	12	17.00	12.00 (4.00)
5.	Dodo Wedera	44	15.61	20.00 (4.00)
6.	Ellen	33	34.40	30.00 (5.00)
7.	Ellen Golode	15	25.24	27.00 (5.00)
8.	Koka Dam	10	15.37	12.50 (4.00)
9.	Melka Hida	15	29.10	28.00 (5.00)
10.	Sire Robi	32	21.55	25.50 (5.00)
11.	Tere	24	8.98	15.00 (4.00)
	Mean	23	19.06	-

Source; Tegene, et al., [52]; Values in parenthesis indicates disease severity rated based on 1 to 6 scale.

grounds, delayed access to markets and increased costs (effort and materials) of fishing. The average weight of fish catch was 28 kilograms of fish/day per an individual fisherman during spawning season before water hyacinth infestation however, it decreased by 46.4% (13 kilograms/day) at the same period after water hyacinth infestation in Lake Tana.

Effects on navigation, irrigation, and hydropower

Water hyacinth disrupts water transportation by forming thick mats covering the surface of water bodies, preventing people's access to schools, communication, health facilities, fishing grounds, and even local markets. Mbula [31] reported that, in the Kafubu river in Zambia, precious time is wasted in setting the fishing gears in water due to the presence of the plant's mats, while the weed also reduces the amount of water needed for irrigation and blocks channels of irrigation. The proliferation of water hyacinth is reported to significantly hamper fishing and fish trading activities in the neighborhood of River Tano in Ghana [32]. Worku and Sahile [33] reported the impacts of water hyacinth on Lake Tana in Ethiopia. The lake is said to provide economic benefits to individuals living in its surroundings in the form of fishing and recreational facilities.

Invasion of this lake by water hyacinth is said to be gradually taking away this source of livelihood from residents around the lake by hampering transportation on the lake. Honlah, et al. [25] conducted a cross-sectional research on the impact of water hyacinth on the movement of students who use River Tano and Abby Tano Lagoon in Ghana as a means of transportation. The invasion of the water bodies by water hyacinth invasion was reported to impede the smooth transport of the students who uses River Tano and Abby Tano Lagoon in Ghana as a means of transportation. So that they may have to remain at home during the peak of the weed invasion, thereby negatively affecting the human resource base of the people. Hydropower systems are rendered inefficient from the impacts of water hyacinth. Owen Falls hydropower system on Lake Victoria has been affected by the invasion of this aquatic weed, and power generation is reduced due to the weed's fast growth and multiplication [24].

Impact on crop production

The effect of water hyacinth on the farming activities was observed along River Tano and Tano Lagoon, Ghana [25]. Crop production is the main source of food and means of income generation of the people living in the Lake Tana area though the infestation of water hyacinth in has affected crop production of 70% of interviewed farmers during 2014/15 and 2016/17 cropping seasons Likewise, the crops production of close to 70% of farmers was affected by water hyacinth in the Rift Valley of Ethiopia [34].

Management Options of Water Hyacinth

The invasion of water hyacinth on most water bodies is largely a result of a combination of a number of different and accumulative factors. These include high concentration of nutrients, absence of natural enemies, its use for ornamental purposes and failure on the part of responsible authorities to implement sustainable ways to control the plant and can't be accurately addressed using a single control mechanism. There is need for the implementation of a number of strategies that complement each other so as to effectively reduce water hyacinth infestation to its lowest possible levels possible which are manageable. An integrated management approach is one such system that has been reported to have been successfully utilized in some countries [35,36]. However, existing methods have often been insufficient to restrict the aggressive propagation of the weed and viability of its seeds despite substantial monetary investments over the years [37], mainly due to lack of continued policy and management support by governments.

Nutrient control

Nutrient requirement has been highlighted as one of the factors that affect the growth of water hyacinth. The water weed is known to thrive in environments where the water is highly polluted with sewerage waste material which is normally rich in phosphates and nitrates. It is therefore, paramount to keep nutrient levels low to prevent proliferation of the water hyacinth. Mallya, et al., [35] reported that the identification of sources discharging nutrients into Lake Victoria in Tanzania is one of the vital steps that led to 70% reduction of water hyacinth cover. They highlight that nutrient enrichment was controlled by way of constructing wetlands. The effectiveness of artificial wetlands in the removal of nitrates and phosphates has been well documented by different scholars. Juang and Chen [38] observed a 47% decrease in ammonium nitrogen concentration in river water treated by an artificial wetland. In another study done by Lu, et al., [39] a constructed wetland managed to decrease nitrogen and phosphorus concentrations by 21.7% and 23% respectively. This was for the purification of nutrient filled duck farm wastewater. Nitrogen removal within the wetlands is by way of plant absorption and the various processes which are part of the nitrogen cycle such as denitrification [40,41].

Physical control

There are basically two types of physical control, manual and mechanical both offering temporary short term control of the water hyacinth [42]. Manual control entails the use of labor to remove the water hyacinth growth from water bodies. It is regarded as being labor intensive with huge financial implications [42]. This can only be utilized for small infestations. Mechanical control involves the use of machinery such as harvesters and boats to remove hyacinth and is normally used for large infestations. Both control mechanisms have been reported to have been successfully utilized in integrated management programe [35,43].

Manual removal can be best applied at points which have been observed to be shallow during the dry seasons where people can easily walk in and pull out water hyacinth by hand. Employing machines like weed harvesters, crusher boats, and destruction boats prove expensive, approximately USD600-1,200 per hectare [20] as well as unpractical for areas larger than a hectare given the rapid rate of increase of the weed. There may also be additional fees for disposal of plant material. Physical methods for control of water hyacinth also involve drainage of the water body, manual removal of the weeds or pulling through nets [18]. In Europe, management costs to remove 200,000 tonnes of the plant along 75 km in the Guadiana river basin on the Portuguese-Spanish border amounted to EUR 14,680,000 between 2005 and 2008. Dagno, et al., [44] reported that mechanical management of the weed in Mali cost around US$ 80,000-100,000 per year. Maintaining a clear passage for ships to dock at Port Bell in Uganda is estimated to cost US$ 3-5 million per year [45]. Yet, while mechanical removal has been effective to a considerable extent, the infestations soon return because shredded bunch of the weed are carried by waves to other unaffected areas where they establish and start proliferating [46].

Chemical control

One of the methods of water hyacinth management is with the help of chemicals, such as herbicides. However, this brings with it one great danger, certainly with large-scale or incompetent use. This is how the extensive use of the defoliation chemical 'Agent Orange' (2.4-dichlorophenoxyacetate acid) in the Sudan - the consequences of which are well-known from the Vietnam War - led to serious illness amongst local fishermen. A generally cheaper method has been used worldwide to reduce water hyacinth populations through the use of chemical herbicides (such as Paraquat, Diquat, Glyphosate, Amitrole, 2, 4-D acid) [20]. However, their use directly interferes with the biocontrol agents currently deployed against this weed. Long term use may degrade water quality and put aquatic life at risk [47] with significant socioeconomic impacts if beneficial or designated uses of the water body such as drinking and preparing food are affected [9]. Considering that hundreds of thousands of hectares have been invaded by the weed, it is unlikely that it will be controlled by chemical means alone [8].

Biological control

One long lasting and sustainable way of controlling water hyacinth infestation is by way of importing its natural enemies from its native area and releasing them on the plant [48]. This has been successfully utilized in Tanzania where it was used as part of an integrated management control system that successfully led to the reduction of water hyacinth cover by 70% [35]. Biological agents that have been used include the *Neochetina* weevils whose introduction made a sound impact on the weed cover on Lake Chivero in the 1980's and the Manyame River systems [49]. In recent years, focus has shifted to natural enemies of water hyacinth including plant pathogens [9,20]. The aim of any biological control is not to eradicate the weed, but to reduce its abundance to a level where it is no longer problematic. While there exists several native enemies of water hyacinth, two South American weevil beetles (*Neochetina eichhorniae* and *Neochetina bruchi*) and two water hyacinth moth species (Niphograpta albiguttalis and Xubida infusella) have had effective long-term control of water hyacinth in many countries, notably at Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin [9]. The weevils reduce water hyacinth vigour by decreasing plant size, vegetative reproduction, and flower and seed production. They also facilitate the transfer and ingress of deleterious microorganisms associated with the weevils (both fungi and bacteria) into the plant tissues [50].

Reduction by utilization

Research into the utilization and related technologies for the control of water hyacinth have been tested over the last few decades [30]. It is being speculated that the biomass can be used in waste water treatment, heavy metal and dye remediation, as substrate for bioethanol and biogas production, electricity generation, industrial uses, medicines, animal feed, agriculture and sustainable development [18]. However, seldom does utilization provide a sustained solution to the spread and impact of water hyacinth, and in fact could provide a perverse incentive to maintain the invasive plant to the detriment of the environment and production systems at high economic and social costs.

Potential Pathogenic Fungi to Water Hyacinth in Ethiopia

Biological control of water hyacinth, using natural enemies, has been reported to be the most economical and sustainable method of control because it persists with little ongoing cost and no negative environmental impacts [51]. Biological control of water hyacinth, which involves the use of natural enemies (i.e. insects and fungal pathogens) has been reported to be the most economical and sustainable method of control [5]. Fungal pathogens have gained acceptance as a practical, safe, environmentally friendly weed management method in agro-ecosystems worldwide [10] although their use has not been adopted in Ethiopia.

Recommendations have been made to integrate fungal pathogens with insects to improve biological control of water hyacinth due to the insect feeding damage facilitating pathogenic infections of water hyacinth leaves [11]. Attempts have been made to identify potential biological agents in Ethiopia. Earlier studies indicate that some fungal as well as insect bioagents are available in the country (Stroud, 1991). For instance, a survey carried out in the Gambella region (1970's) revealed that fungus Cercospora rodmanii affected water hyacinth by about 5 to 15% in place of infestation [4]. Likewise, Firehun, et al. (2006) reported that fungal pathogen, *Fusarium equiseti* (Corda) Sacc was found infecting water hyacinth at Wonji-Shoa Sugar Estate water reservoirs. The damage caused by the fungus in the field as well as in green house on the weed was promising. Moreover, Tegene, et al. [52] reported that nineteen fungal species were identified of which 9 of them viz *Alternaria alternata*, *Alternaria geophila*, *Ascochyta chartarum*, *Cochliobolus carbonum*, *Epicoccum nigrum*, *Fusarium chlamydosporium*, *Fusarium equiseti*, *Pythium ultimum* and *Stemphylium vesicarum* were found being virulent with the highest severity of 5.67 recorded from *Pythium ultimum*. Moreover, disclosed that 25 water hyacinth pathogenic fungal species belonging to 9 genera were identified of which *Alternaria tenuissima* (23.5%) and *Aalternaria alternata* (26.5%) were the most prevalent. On the other hand, Admas, et al. [53] explained that *Rhizoctonia* spp followed by *Fusarium* spp was resulted a complete drying of water hyacinth with a severity value of 100% and 78.6% Dinknesh, et al. [54].

Host Specificity of fungal pathogen and its effect on growth of water hyacinth

The pathogenic fungi collected from rift valley, Ethiopia showed a severe reduction in plant height (48%-55%), root length (45%-50%), fresh (53%-67%) and dry weight (60%-72%) by *Alternaria alternata*, *Neofusicoccum parvum* and *Alternaria tenuissima.* The maximum relative reduction of water hyacinth fresh weight, dry weight, plant height, and root length was obtained from *Alternaria alternate* with the value of 67.39%, 72.49%, 55.38% and 50.0% respectively followed by *Neofusicoccum parvum* having 61.21%, 68.92%, 55.29%, and 48.99% reduction percentage for fresh weight, dry weight, plant height and root length respectively. With regarding to the host specificity of the fungal pathogen, *Fusarium equiseti* and *Fusarium oxysporum*, are pathogenic to agricultural crops whereas *Alternaria alternata*, *Alternaria* sp., *Alternaria tenuissima* and *Neofisicoccum parvum*) are pathogenic to water hyacinth and water lettuce However, reported *Alternaria alternata* as a worldwide pathogen of water hyacinth.

Conclusion and Future Prospects

Despite the presence of highly virulent fungal pathogens against water hyacinth, none of them have been utilized to control this aquatic invasive weed in Ethiopia till now.

In Ethiopia, there is a huge occurrence and potential of bio control agent for effective management of water hyacinth. Hence, detail evaluation of the most potential pathogenic fungi in water hyacinth management in the country is crucial and verification of virulent pathogen followed by host specificity test. The invasive nature of water hyacinth makes it an environmental challenge; however, the prospects of the weed can't be ignored. It may be better not to generalize the weed as a menace but rather to look at the peculiarity of each situation where the weed grows. In situations where facilities exist to utilize the potentials of this plant, efforts should be geared toward harnessing and optimizing its growth. Where the reverse is the case, a combination of the most effective control method that is not too slow and cost-effective should be considered in managing the growth of the weed.

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