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Problems of Invasive Species of Water Hyacinth (*Eichhornia Crassipes* [Mart.] Solms) in Cameroon with Special Reference to Its Eradication and Valorization: A Bibliographical Review

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Abstract

Originally from South America, the water hyacinth (*Eichhornia crassipes* [Mart.] Solms) has been introduced in several parts of the world as an ornamental plant and particularly in Cameroon. However, this plant later became one of the most dangerous freshwater aquatic plant species. For this, it has been the subject of a global reflection because due to its rapid spread and its rapid development, it is at the origin of the difficulties encountered in the sector of river or maritime navigation, irrigation and life in an aquatic environment. In Cameroon, we observe a lot of damage to the environment and local economy caused by water hyacinth pollution of lakes and rivers. However, its infestation can be controlled by physical, chemical and biological methods of control which prove to be better adapted to a sustainable management of the hyacinth. Alongside these methods, there is an urgent need to reflect on its promotion, including its popularization, which will offer the populations of the areas concerned opportunities and impetus towards a change in pro-environmental behavior in the management of national heritage. This research work examines current research activities on the subject, based on the scientific and technological relevance of *Eichhornia crassipes* in the light of existing knowledge. In a specific way, this paper will focus on the systematic and the morphological description of the water hyacinth, the dispersion and the problems created by its presence, the means of control and valorization of the water hyacinth.

Keywords: *Eichhornia crassipes*, pollution, control methods, valorization

1. Introduction

Invasive in nature, Water Hyacinth (*E. crassipes* [Mart.] Solms) has been extensively addressed in reviews due to its negative environmental and economic impact (Dersseh *and al.,* 2019; Villamagna *and al.,* 2010). Originating from the Amazon, this notorious macrophyte (Villamagna *and al.,* 2010; Eid *and al.,* 2017), is one of the most widespread invasive macrophytes in the world, especially in tropical countries. Fresh water bodies suffers the presence of this species due to lack of its natural enemies to curtail their reproductive potential. Water hyacinth is a good effective colonizer and has become a serious worldwide invader (Barrett, 2011). In addition, the water hyacinth's free-floating habit makes it a very effective colonizer of newly invaded fresh water bodies. It rapidly out competes other plant species and forms dense floating mats, which may completely cover the water surface. Consequently, the often multi-functional use of infested canals, rivers and lakes becomes seriously hampered (Hill *and al.,* 2011). It is capable of producing large quantities of biomass and by colonizing very large environments, it is considered an invasive species in most of the countries where they are established. The presence of Water Hyacinth in infested regions of tropical and subtropical countries has caused serious economic and ecological consequences (Ghabbour *and al.,* 2004; Center *and al.,* 2005). Thus, through its invasive nature, it alters the water balance of the entire regions and hinders fishing activities, which has an impact on the health and standard of living of populations. It therefore constitutes one of the most important scourges in freshwater bodies of the tropics, in areas where they have been introduced. The consequences of this biological invasion on the aquatic ecosystem and human activities are not trivial (Adjahatode *and al.,* 2016). This flooding of rivers is a current and permanent phenomenon (Karim *and al.,* 2006). As a result, water hyacinth (*E. crassipes*) also causes enormous water loss through evapotranspiration (Perez *and al.,* 2011). It promotes the proliferation of diseases such as bilharzia and malaria. Indeed, their larvae easily develop under its tufts on the banks of rivers and in bays (Harley, 1990). They quickly form large dense mats and invade the banks of rivers.

In Cameroon, many rivers and water paths are covered with this macrophyte, *E. crassipes* [Mart.] Solms. These mats grow haphazardly and reduce the amount of oxygen and light reaching underwater, which is detrimental to many aquatic species. These macrophytes limits river transport, fishing and obstruct the water intakes by hydroelectric dams and irrigation networks (Gutierrez *and al.,* 1994; 1996). In addition, both the proliferation of water hyacinth and pollution are very competitive, depleting the water in phytoplankton, thus reducing the production of aquatic ecosystems. In this regard, on death, it releases not only organic matter, but also pollutants that they trapped. The consequence is the imbalance and reduction or even the extinction of the least tolerant species. Furthermore, it is known that macrophytes extract the nutrients necessary for building their organs from the surrounding environment (water, sediment). The most important of these nutrients are nitrogen and phosphorus. This extraction therefore removes some of the available nutrients from the environment and contributes to what has long been called "self-purification" of aquatic environments (Boutin & Dutartre, 2014). Likewise, by preventing the penetration of solar radiation, the dense carpet of hyacinth decreases photosynthesis of primary producers at the base of food chains. The decomposition of dead leaves makes the environment anoxic, thus leading to eutrophication of the body of water and depriving them of oxygen middle species. We thus witness the suffocation of aquatic animals living in environments of large proliferations water hyacinth. This state of affairs affects the physico-chemical quality and organoleptic of the water then reduces the fishing stocks (Adjahatode *and al.,* 2016). In addition, with the development of the human population, aquatic environments have increasingly served as receptors for domestic effluents with increasingly visible consequences. The increasing protection of rivers has therefore led to a little over a century to the creation of well-known purification systems (Boutin & Dutartre, 2014). During the last ten years, the rapid spread of invasive aquatic plants, particularly in tropical Africa and especially in Cameroon, has caused ecological and hydro-agricultural crises; especially since they are surrounded by inhabited areas, agricultural land and roads.

Most of Cameroon's wetlands are used for aquaculture biodiversity and constitute a resource for subsistence and income for the riparian populations (Ndjouondo *and al.,* 2017). But, in recent years, many rivers in Cameroon such as the Wouri, the NKam, the Moungo, the Nyong and their tributaries have been invaded by invasive plants, in particular the water hyacinth. These rivers are vital compartments containing many natural resources (fauna, flora, microorganisms, mineral elements) (Tchiaze & Priso, 2016). Only, in the context of the preservation and protection of aquatic ecosystems, the presence of *E. crassipes* appears to be dangerous and needs to be controlled (Karim *and al.,* 2006). The sustainable management of the hyacinth infestation has focused on biological and physical control with a view to their eventual recovery. In this paper, we will examine the problems and characteristics of the invasive species of Water Hyacinth (*E. crassipes*) in Cameroon with special reference to eradication and valorization. Recommendations for further research have been made.

2. Methodology

For this study, most of the information was collected from documents reporting on previous work on invasive plants in general and on water hyacinth in particular. Specifically, this bibliographic research involved identifying, reading and collecting the referenced data that could help in the drafting of this document.

3. Results and Discussion

3.1 Systematic and Morphological Description of Water Hyacinth

3.1.1 Taxonomy of Water Hyacinth

According to Qaisar *and al.,* (2005), the water hyacinth is a perennial herbaceous monocotyledon. It belongs to the Division of Magnoliophyta, class of Liliopsida, subclass of Commelinidae, Super-Order of Commelinanae, order of Pontederiales, Family of Pontederiaceae, genus of *Eichhornia*, specific epithet *crassipes* (Martius) Solms-Laubach. There are eight other species of the genus Eichhornia (Hill *and al.,* 2011) among which are *E. paniculata, E. paradoxa, E. heterosperma, E. diversifolia, E. venezuelensis, E. azurea*, mainly neo-tropical which are confined to South America. However, Barrett, (2011) corroborates these information and inform that none have shown the dramatic spread exhibited by the Water hycianth during the past century, despite the fact that several of them have been introduced to various regions as pond ornamental.

3.1.2 Chemical Structure of Water Hyacinth

According to Liu *and al.* (2017) and Huang *and al.* (2016) have presented the chemical composition of Water Hyacinth biomass, in which both kinds of literature showed the differences in the content of C, H, O, N and S. Since the biomass physicochemical properties were highly influenced by the environment where it grows, therefore, its physicochemical properties may be varied by different place and conditions. Moreover, according to Sukarni Sukarni *and al.* (2019), chemical elements of water hyacinth are C, O, Na, Mg, Al, Zr, Cl, K, Ca, Si, Ti, and Fe revealing dominant elements, i.e., oxygen and carbon for 49.50% and 14.46%, respectively. The proximate analysis revealed that its moisture, volatile matter, fixed carbon, and ash content were 4.9, 61.2, 13.8, 20.1 (weight %), respectively. This biomass has gross calorific value (GCV) that tested with an adiabatic bomb calorimeter of 14.46 MJ/kg. Since the water hyacinth biomass has a relatively high volatile content and a low heating value, it is reasonable that water hyacinth might suitably for combustion with coal to increase the coal's reactivity during the combustion process.

3.1.3 Morphological Description of Water Hyacinth

E. crassipes Martius (Solms-Laubach) have been described by different authors (Barrett, 2011; Hill *and al.,* 2011). Water hycianth is a free-floating perennial plant (herb less than 30 cm tall) that is often rooted in mud on open water and more especially along lakes and banks of rivers. The growth form is variable and produced inflorescences with up to 23 flowers (Hill *and al.,* 2011). Usually, each herb has rosette leaves not more than ten encored to a Rhizome. Water hyacinth is tristylous and in its native range population contain the three floral morphs (referred to as long-, mid-, and short-styled forms) that characterizes this particular outcrossing system (Barrett, 2011). There is an elongated petiole of up to 1.5 m in length that grows in dense mats with well-developed fibrous root system. Both sexual and asexual reproduction has been recorded (Barrett, 2011), with the species utilizing the asexual mode as it produces daughter plants or ramets because the plant has the potential to multiply every two weeks when under uncrowded eutrophic waters condition. Optimum temperature for growth ranges between 25-30°C despite high temperatures in some countries of sub-Saharan Africa where it grows abundantly. In effect, growth ceases either above 40°C or below 10°C, but short periods at freezing may be tolerated. Water hyacinth, or *Eichhornia crassipes* (Mart.) Solms, from the family Pontederiaceae, is a free-floating aquatic plant that commonly grows in inland freshwater bodies such as lakes, rivers, streams, ponds and wetlands. The plant has broad, wide canopy-like waxy leaves and purple clustered flowers that grow in spikes. The petioles of the plant appear bulbous with air-sacs that help make it buoyant. The plant varies in height from a few centimeters to nearly a meter, while the leaves may be around 15–20 cm in length and width (Jafari, 2010). The plant can sometimes become rooted when it lodges in muddy, shallow waters and the flowers may be blue or white (Jafari, 2010)

Leaves with bulbous petioles are dominant in open water while elongated petioles (1.5 m high) predominate in dense colonies (Center *and al.,* 2005). The size and morphology of the plant varies considerably depending on the concentrations of nutrients, especially phosphorus and nitrogen. The root system of water hyacinth is dark blue in color with numerous runners at the end of which new plants form. Sometimes *E. crassipes* can reach a height of 1.5 m when measured from the tall flower to the upper root (Center *and al.,* 2005).

Figure 1. Water hyacinth on the lake in the commune of Sô-Ava in Benin. (Dan, 2012) on the left (Moderately clonal population) while on the right sexual population

In Cameroon, the identified flora of freshwater rivers is beginning to be the subject of inventories and it is clear that despite these efforts, data on the conservation status of freshwater plants paradoxically remains scarce (Dibong *and al.,* 2014).

3.2 Dispersion and Problems Created by Water Hyacinth

3.2.1 Dispersion of Water Hyacinth

The water hyacinth, *E. crassipes* (Pontederiaceae) was introduced in Africa at the beginning of the 20th century, in the Congo basin as an ornamental plant for ponds by Belgian colonists. This floating aquatic macrophyte thrives on the surface or on the mud of streams at a high and amazing rate. In this regard, the urban development inherent in demographic growth and industrialization (extension of the port, dumping of toxic substances) is at the origin of an anarchic growth and densification of working-class urban districts. According to FAO (2006), the urbanization rate of a city like Douala increased from 37% in 1987 to 55% in 2004 and includes nearly 90% of businesses. Some streams are transformed into outlets and later used to grow Amaranthus hybridus, Arachis hypogaea, Ipomoea batatas, Zea mays. Very often, we see a substitution of the lesser known species by others which are more adapted to the conditions of the environment. Many species have replaced the characteristic species of swamps, mangroves and other rivers in the coastal region, thus altering the initial physiognomy of these ecosystems (Tchiaze & Priso, 2016). This is particularly the case with certain macrophytes that invade water and spread from one region to another. This flooding of rivers is a current and permanent phenomenon (Karim *and al.,* 2006).

3.2.2 Species Invasiveness, Impact and Adaptability in Cameroon

During the last ten years, the propagation of the water hyacinth has caused ecological and hydro-agricultural crises in Africa (Dagno *and al.,* 2007). Many nations continue to grapple with the complex and costly issues associated with invasive alien species. For example, the cost of water hyacinth problems in African countries is between US $ 20 million and US $ 50 million per year (CAB International, 2004). Among aquatic herbaceous plants, water hyacinth (*E. crassipes*) causes enormous water loss by evapotranspiration, forming large dense mats reducing the amount of oxygen and other mineral elements necessary for growth (Perez *and al.,* 2011), alters the water balance of entire regions, hinders fishing activities, which have an impact on the health and standard of living of populations. It should be noted that proliferation of macrophytes due to pollution deplete the water in phytoplankton, thus reducing the production of aquatic ecosystems. In this regard, when *E. crassipes* dies, it releases not only organic matter, but also the pollutants it trapped. The consequence is the imbalance and the decrease or even the extinction of certain less tolerant species (Tchiaze & Priso, 2016). The ease of propagation of Water Hyacinth's in different environmental conditions and its mobility make it difficult to control. This difficulty is important as this plant is recognized as an "aquatic plague". It has become one of the most important plagues of tropical freshwater bodies, in areas where it has been introduced. It quickly forms large dense mats and the invasion of the banks of the Wouri or its arms is an indisputable example where these mats reduce the amount of oxygen and light arriving underwater, which is detrimental for many aquatic species. (Tchiaze & Priso, 2016). It slows down river transport, fishing and obstructs the water intakes of hydroelectric dams and irrigation networks (Gutierrrez *and al.,* 1994, 1996). Very competitive, it depletes the water in phytoplankton, thus reducing the production of aquatic ecosystems. Water hyacinth depletes biodiversity and is dangerous to human health. It promotes the proliferation of diseases such as bilharzia and malaria. Indeed, their larvae easily develop under its tufts on the banks of rivers and in bays (Harley, 1990). Since the beginning of this century, very few invasive species were assessed for the potential of being introduced, established, spread and causing damage in Cameroon ecosystems. Water hyacinth invasion capacity and the underlying mechanisms are ongoing.

As an invasive plant, Water hyacinth has shown to have a formidable growth rates elsewhere and was observed to some localities like Douala, Nyong, etc. Under favorable condition of climate and nutrient availability. Barrett (2011) noted that ten water hyacinth plants could produce a 0.4 ha mat of floating plants in eight month. Moreover, Jiang *and al*. (2017), water hyacinth can have

- Seven-fold increase in spread in 50 days (India);
- edge of the mat extends by 60 cm per month (USA);
- 2 plants can multiply to 1,200 in 120 days;
- 1 plant can multiply to 65,000 in a normal spring season (Louisiana);
- surface area increases by an average of 8% per day (USA);
- the cover can double every 6.2 days;
- 50 % increase in weight can occur in 7 days.

Finally, Hill *and al.* (2011) revealed that water hyacinth doubles every 11-18 days under suitable conditions. More than 40 000 Ha of dams, lakes, canals and drains have been infested with water hyacinth (*E. crassipes*) in Mexico (Gutiérrez and *al.,* 1996). Usually, in the absence of low levels of water fluctuation by Water hyacinth like in its native range, the species uses daughter rosettes clonal and growth occurs, which favors long-distance dispersal in water current. Outcrossing system can be other adaptation invasive trait of the water hyacinth especially in its native range (Lowland South America, Brazil and Argentina) as Barrett (2011) noticed that pollination mediated by specialized bees (conspecific pollen parent) occurs when water level fluctuations allow seeds to germinate and established on riverbanks. Flowering asynchrony may also be attributed as underpinning mechanism trait of water hyacinth invasion like in the case of Nypa palm observed by Moudingo (Thesis unpublished). Not all seeds produced and introduced will generally develop due to the periodic water condition. Canadian pondered (*Elodea Canadensis*, Hydrocharitiacaea) and Japanese knotweed (*Fallopia japonica*, Polygonacea) also exhibited limited or absent opportunities for sexual reproduction events like water hyacinth (Barrett, 2011). With such prodigious growth rates for water hyacinth, a relative significance of different anatomical and physiological adaptation and invasion strategies may include allelopathy nature, energy-use strategy/capacity, clonal integration (Jiang *and al.,* 2017).

3.2.3 Overview on the Spread of Water Hyacinth in Cameroon

One of the rivers mostly affected by this phenomenon of Water Hyacinth colonization is the Nyong River. Indeed, this river is undergoing a continuous degradation under the combined effect of anthropogenic and climatic factors, with the consequences of the erosion of aquatic biodiversity, the uncontrolled and super numeral development of certain invasive plants, the scarcity of water resources, insecurity in food, declining income and rural exodus (Anonymous, 2014). Indeed, (Dibong *and al.,* 2014) specified on this subject that among the many problems that affect lentic and lotic freshwater environments we have pollution of agricultural or industrial origin, road and mining earthworks, intensive local fishing, drying out linked to climate change, siltation due to deforestation of watersheds and the proliferation of invasive species. To completed these informations, Mbouano, (2006) concludes after a study that habitat loss is the second factor leading to the disappearance of local species after the invasion of invasive species. Nouga *and al.* (2017) for their part asserted that on the Nyong River, the obstruction of the navigable waterway contributes to the decrease in fishing yield, water accidents, congestion and reduction in speed of the water current, to the inhibition of the normal circulation of water by modification of the water bodies and to the reduction of the navigable water course which makes it inaccessible, hindering the extraction of sand. This obstruction is the main cause of reduced swimming activities, canoe races, transport and customs in the river (Nguelo, 2007). This congestion of the watercourse has a strong impact on sand extraction and the other difficulties linked to it (Ndjouondo *and al*., 2017). Kouam (2013) stated that Lake Nkolbisson is currently invaded by water hyacinths. The colonization of this lake by plants has led to the cessation of fishing activities that were still practiced in the early 1980s. In addition, the proliferation of mosquitoes is more recurrent in the villages surrounding the Nyong River, because according to (Fogwé & Tchotsoua, 2007) during floods due to the invasion of the river, water besieges the villages and during the dry season, the water patches stagnate and increase the proliferation of mosquitoes. Also, the stopping of swimming competitions and canoe races on this watercourse is mainly justified by the congestion of invasive plants which have reduced the navigable space of the watercourse thus constituting the cause of reduction of aesthetics and cultural activities in the river (Fogwé, 2005). Taking into account the damage caused by invasive plant species in the Nyong River, the majority of actors request their total removal for the facilitation of daily activities (Nouga *and al.,* 2017).

Figure 2. Lac of Nkolbisson in high eutrophization phase (Kouam, 2013)

3.3 Means of Control and Valorization of Water Hyacinth

3.3.1 Means of Control of Water Hyacinth

The ease of propagation of some macrophyte species under different environmental conditions and its mobility can make it difficult to control. This difficulty is important as they are recognized as an "aquatic plague". Management strategy and techniques have been developed for some invasive plants especially in their native habitat. Localized efforts geared towards the removal of aquatic invasive species, like the water hyacinth by the Water Task Group, an NGO based in Douala, proved to be difficult and futile (Moudingo *and al.,* 2020). Barrett (2011) stated that Water hyacinth's aggressive behavior is principally the results of its prolific powers of asexual (sexual) reproduction through clonal growth, combined with its free floating habit. Different methods have been employed to fight this species including mechanical, biological and chemical methods. Mechanical methods have by far been employed through: mechanical weeding, drainage, clearance, maintaining removed stocks. Although it is hoped that biological control will eventually be capable of achieving the necessary level of control of *E. crassipes*, there is likely to be scope for the integration of physical and chemical methods with biological methods on a local basis, to help speed the achievement of control. Introducing and releasing natural enemies is an environmental-friendly and sustainable approach for control of invasive species (Hill *and al.,* 2011; Jiang *and al.,* 2017). Natural enemies including water hyacinth weevils *Neochetina eichhorniae* Warner and *N. bruchi* Hustache (Coleoptera: Curculionidae) butterflies have been used to reduce water hyacinth spread at least 25 % after two years (Jiang *and al.,* 2017). The current observation of the growth rate of the water hyacinth shows that the Wouri River and its tributaries will be likely flooded within a decade if nothing is done. Thus, for adequate management, the following plan is recommended:

- Mechanical control: can be carried out in different ways - manual harvesting by net and fork from the shore, harvesting by conveyor belt, harvesting by harvesting boat;

- dredging of colonized rivers in order to widen their beds following the installation of invasive plants;

- regular clearing and flush-cutting of species present around watercourses for permanent control;

- Harvested water hyacinths left to dry on land can quickly wilt and will, in time, be naturally composted. Cleared land with a pile of water hyacinth leftovers will quickly enter secondary succession driven by the nutrients provided by the composted weed through natural fertilization. Rich in organic nutrients, water hyacinth consists of more than 70% organic matter on a dry basis (Jafari, 2010)

On the Nyong River in Cameroon, the physical control method (mechanical uprooting) is the most used because it is more efficient and helps fight unemployment through the use of local labor. The "cut-cut" method is also considered (Nouga *and al.,* 2017). In addition, the actors recall that the best period to carry out this work is the rainy season because the water current will facilitate the transport of cut invasive plants (Nouga *and al.,* 2017). All of these actions are carried out with the aim of eradicating invasive aquatic plants. Manual and mechanical removal are practices though costly as short term vision. Almost 100 different insect species and a comparable number of pathogens have been recorded as attacking *E. crassipes* that can be used. An example of a well-integrated control approach (in Mexico), South Africa, Argentina and USA (Barrett, 2011; Jiang *and al.,* 2017).

3.3.2 Valorization of Water Hyacinth

Since 1970, water hyacinth has been used with the dual objective of purifying polluted water responsible for eutrophication and of exploiting the very abundant biomass thus produced (Sauze, 1983). According to **(**Irina Harun, and al., 2021), Water Hyacinth can be valorized in different forms as indicated:

Water Hyacinth for Feeds: Water hyacinth has been studied for its nutritional value and potential use as feed for livestock, poultries, and fish (Bai *and al.,* 2017; Hossain *and al.,* 2015; Okoye *and al.,* 2000; Wimalarathne *and al.,* 2019). Its nutritive attributes for example, its high cellulose, hemicellulose and crude protein content make it suitable for use as a substitute or an additive for animal feeds (Wimalarathne *and al.,* 2019). Additionally, water hyacinth nutrient contents were proven to be independent of its place of origin and remain constant at the same levels, even if collected from different geographical areas or water sources (Hossain *and al.,* 2015; Mako *and al.,* 2011). Although normally the whole plant is used as feed, some users omit the roots to avoid possible metal contamination, even when the metal concentration was found to be below the maximum permissible limit (Moses *and al.,* 2021). In general, leafy meal was observed to be more preferable, as the water hyacinth leaf protein content accounts for about 50% (per dry weight) of its total nutritional quality (Adeyemi *and al.,* 2016). In Cameroon, the work of Tchiaze and Priso (2016) on the Wouri river showed that in water hyacinth, the nutrient contents vary significantly from one part to another. Indeed, the roots and leaves of the plant each have a very specific role in the physiology of the plant: the roots selectively draw mineral substances from the soil (raw sap) which will be used at the level of the leaves through the chlorophyll synthesis for the production of organic substances (lipids, carbohydrates, proteins). This is the reason why the roots are richer in ash, while the leaves and stems are richer in organic substances (Taffouo *and al.,* 2008). The percentage of proteins is higher in the leaves and are obtained in sites receiving many alteragens, some of which increase the rate of nitrogenous substances easily assimilated by plants in these two sites (Priso *and al.,* 2010). Tchiaze and Priso (2016) also reveal that the roots taken from sites located in urban areas also stand out for their particular richness in ash compared to those from the rural area, thus testifying to the many alteragens that are dumped there. Analysis of macronutrients in the leaves, stems and roots of *E. crassipes* showed that this plant is very rich in water, and that the values of metabolizable energy and carbohydrate content are high. The ash contents are higher in the roots. On the other hand, the lipids are present in the form of traces as well as the proteins at rates less than 20%. It could therefore be a source of raw material for the extraction of biogas, the manufacture of compost to enrich the soil (Almoustapha *and al.,* 2008), the making of works of art and animal feed (Gupta, 1998). For a sustainable management of these resources, it is important to have instruments capable of storing, processing, modeling and restoring data in various forms.

Water Hyacinth for Biofertilisers production: Harvested water hyacinths left dry can quickly wilt and will in time, be naturally composted. Cleared land with a pile of water hyacinth leftovers will quickly enter secondary succession driven by the nutrients provided by the composted weed through natural fertilisation. Rich in organic nutrients, water hyacinth consists of more than 70% organic matter on a dry basis (Jafari, 2010.) and high levels of nitrogen (N), phosphorus (P) and potassium (K) content (Ilo and al., 2020) Water hyacinth can be either mulched (Balasubramanian and al.,2013; Indulekha *and al.,* 2018; Xu *and al.,* 2017), composted (Ali *and al.,* 2020; Lu *and al.,* 2017) vermin composted (Gajalakshmi *and al.,* 2002; Nath & Singh, 2016) or anaerobically digested (Sharma and Suthar, 2020) for biofertilisation purposes. Irina *and al*. (2021) affimed that harvested water hyacinths left to dry on land can quickly wilt and will, in time, be naturally composted. Cleared land with a pile of water hyacinth leftovers will quickly enter secondary succession driven by the nutrients provided by the composted weed through natural fertilisation.

Water Hyacinth in Crafts: Water hyacinth has great potential for use in craft production. Raw material from the dried plant and its fibre can be utilized to make bags, handbags, wallets, flower pots, fashion accessories, mats and many other items (Hidayat *and al.,* 2018; Punitha *and al.,* 2015; Sandeep *and al.,* 2015). According to Rakotoarisoa *and al.* (2016), in selecting the raw materials, the water hyacinth stem length must be at least 50 cm for it to be suitable for handicraft production. They also added that water hyacinth stems are simple to cut and weave due to their size and flexibility. Other than the stem, the dried petioles of water hyacinth are also used to make other forms of handicraft, including coasters, mats, shoes, sandals, belts, wallets and vases, in countries like Indonesia and the Philippines (Patel, 2012). Today, digital technology has enabled the development of home-based enterprises (HBEs) or home industries utilising water hyacinths. For instance, communities around Rawapening in Indonesia utilized overgrowing water hyacinths in online home-based enterprises (Sianturi *and al.,* 2019). The locals use water hyacinths to make products such as bags, sandals and baskets, and furniture like chairs and tables, before marketing them using the internet (Sianturi *and al.,* 2019). In Madagascar, communities traditionally use papyrus for handicraft production; however, water hyacinth is now being used in the production of large and small hats, shopping bags, handbags, sandals and mats (Rakotoarisoa *and al.,* 2016). These products are also being exported to international markets (Rakotoarisoa *and al.,* 2016).

Water Hyacinth as feedstock for Bioenergy production: Water hyacinth has immense potential for use as an energy resource. Due to its dense population and aggressive growth, the utilization of this aquatic weed as an energy feedstock is highly attractive, especially when paired with its potential capacity for phytoremediation and energy production. Furthermore, using this biomass as an energy resource solves the issue of water hyacinth management post-phytoremediation (Ilo *and al.,* 2020). Water hyacinth is abundantly available, biodegradable and characterized as a non-crop plant. This categorizes the biofuels thus produced as second-generation biofuels, alleviating any food versus fuel complications. Its biomass characteristics are promising in terms of energy production; it has a low lignin content (10%) and high cellulose (20%) and hemicellulose (33%) content (Rezania *and al.,* 2015). As the lignin content is low in water hyacinth, the plant is especially suited for utilisation as a bioenergy resource, as this compound hinders the fermentation processes of several commercial yeasts and enzymes (Rezania *and al.,* 2015). Water hyacinth also exhibits a useful C/N ratio within the range of 20:1–30:1, which is appropriate for microbial decomposition processes (Feng *and al.,* 2017). In this subject, Harun *and al.* (2021) think that water hyacinth has immense potential for use as an energy resource.

Biogas production through the anaerobic digestion of Water Hyacinth: Anaerobic digestion is a process whereby organic matter is converted into biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2). Biomethane can then be used as an energy resource for heating, cooking and power generation. This conversion relies on the biochemical activities of bacteria and archaea consortia that break down the complex organic matter into soluble monomers such as amino acids, fatty acids, simple sugars and glycerols, subsequently producing methane. Harun *and al.* (2021) affirmed that from one hectare of water hyacinth and the agricultural residues from one plantation hectare, 3500 m3 of biogas can be produced through anaerobic digestion, which can be used to provide energy for the community, reducing their dependence onthe electricity grid.

Briquette production from Water Hyacinth Biomass: Despite its substantial potential as an energy resource, the direct utilisation of water hyacinth is relatively challenging. Fresh biomass is bulky and has a low density, so its use in conventional burners is uneconomical. Briquetting is a biomass densification process that transforms biomass residues into a cleaner and enhanced solid fuel with higher density and heat intensity (13.1–18.4 MJ/kg) (Li *and al.,* 2021). Raw water hyacinth contains up to 95.5% moisture, which compromises its ability to be combusted as a direct fuel (Jafari, 2010). The advantage of converting biomass into briquettes is that the moisture content can be reduced while its density is increased, which enhances its fuel properties (Rezania *and al.,* 2015). The transformation of water hyacinth biomass into briquettes is also a more environmentally friendly process, as co-firing with coal reduces greenhouse gas emissions (Narayanan & Natarajan, 2007).

Supplying Water hyacinth to Other Industries: According to some reports, water hyacinth has been used as a raw material for bio-based building materials such as thermal insulators (Jaktorn & Jiajitsawat, 2014; Salas-Ruiz *and al.,* 2019) and concrete mixture (Okwadha & Makomele, 2018; Salas-Ruiz & del Mar Barbero-Barrera, 2019). It has also been used in the production of high-value chemicals such as furfurals and hydroxymethylfurfural (HMF), biopolymers and enzymes, as reviewed by Ilo *and al.* (2020) and the production of biochars used in agriculture and low-grade energy sectors (Song *and al.,* 2019; Rahman, 2018). Water hyacinth has other potential bioenergy uses, having been extracted for its phenalenone compounds and sterols for pharmacological purposes (Lalitha *and al.,* 2012) and used for water treatment purposes through phytoremediation (Rezania *and al.,* 2015).

Lag phase detection and monitoring: However, Water Hyacinth is use in monitoring early and lag phase detection and reporting is havoc, and very few organization works to curtail water hyacinth invasion, so there is need for national and field-monitoring systems. Network can use technics such (i) real-time data-collecting; (ii) molecular detecting change ; (iii) chemical pheromone monitoring; (iv) physical monitoring (eg ground penetrating radar) ; and (v) remote data transferring outline by (Wan and Yang, 2016). In view of the opportunity that the water hyacinth can represent, we can ask ourselves the question of why these methods of recovery have not been popularized in Africa, especially in Cameroon? In addition to these advantages that water hyacinth can have, it could have many others (figure 2).

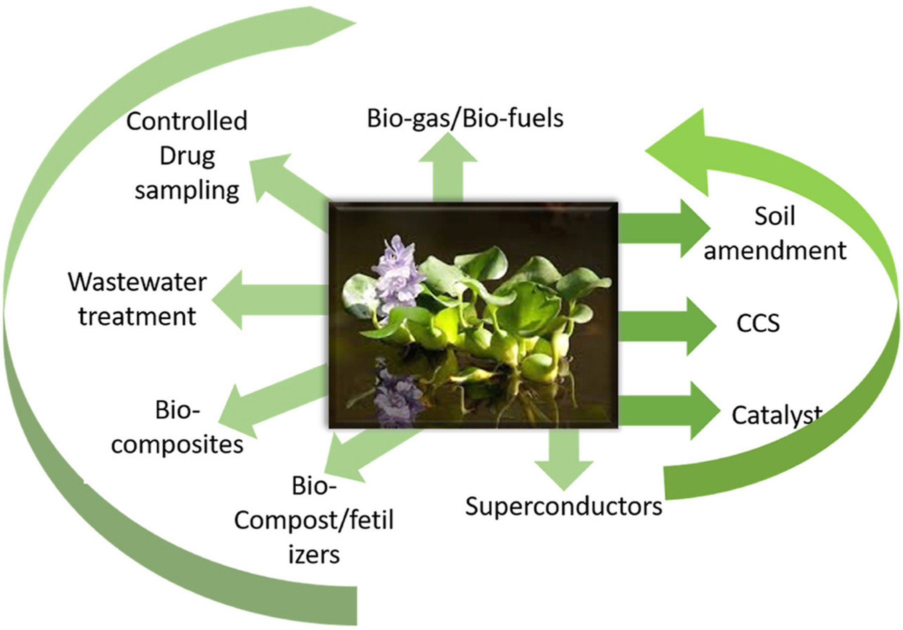

Figure 2. Water hyacinth as a biomass (Gajendra and al., 2020)

4. Conclusion and Recommendations

Water hyacinth (*E. crassipes* [Mart.] Solms) is one of the most widespread invasive macrophytes in tropical countries, particularly in Cameroon. This situation has led decision-makers to take measures aimed at combating these nuisances, in particular by physical, biological or even chemical means. However, physical control beyond providing some control of water hyacinth infestation in the aquatic environment appears to be the most suitable method of getting the most out of this plant. To this end, this method offers the possibility of upgrading it into value-added products with regard to the opportunities it offers, in particular its availability, its morphological and physicochemical structure. However, several recommendations can be made to Cameroonian local administrations, which are advised to create the Early Detection and Rapid Response System (EDRR 3.0) for Invasive Plants. The landscape approach to EDRR, which involves the development of EDRR capacity at all levels of the landscape. In addition, local communities and Non-Governmental Organizations have a real role in detecting and reporting Water Hyacinth to prevent their spread.

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