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RESEARCH ON THE APPLICABILITY OF WATER HYACINTH BIOMASS IN SUSTAINABLE AGRICULTURE

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Abstract: In the context of the increasing reduction of exhaustible sources and in the attempt to identify and capitalize on any possible source of renewable energy, the energy potential of aquatic plants due to the abundance of their biomass was studied. Although aquatic plants are considered invasive, they also have numerous benefits in various fields, such as: agriculture and aquaculture, food and pharmaceutical industries, ecosystem management, ornamental plants. In recent years, biomass as a renewable source has made a significant contribution to energy consumption.This paper presents the varied application of water hyacinth biomass in sustainable agriculture.

Keywords: biomass, renewable energy, agriculture, water hyacinth

1. INTRODUCTION

It is well known that traditional agriculture involves a high consumption of non-renewable resources used for soil cultivation and fertilization. All these actions contribute to the constant decrease in non-renewable sources. Energy production, distribution and consumption certainly have a negative impact on the environment (Marsanich A., 2003). Therefore, renewable energy sources are vital for sustainable development (Goldemberg J. et al., 2004).The efficient use of renewable resources and the minimum consumption of non-renewable resources will cover the risks of agricultural production (Antal J. et al., 2007).To discover alternatives for replacing non-renewable sources, feasible sources of renewable energy have been studied, biomass is the best known of these.

A renewable source, biomass releases CO2 into the environment that other plants use for their development and can be seen as an indirect consumer of solar energy. Its increasing use is due to concerns about the negative impact on the environment and human health. The main sources of biomass come from agricultural residues, animal residues, industrial residues, forestry residues, aquatic crops and sewage (Tursi A. et al., 2019; Keche A. J. et al., 2015).

An important source of biomass is aquatic plants. Although the water hyacinth is considered the most invasive aquatic plant in the world due to its rapid growth and multiplication, the floating macrophyte has a real potential in energy production. The aquatic plant is widespread mainly in tropical and subtropical regions, but can be observed in many other areas, the optimal development temperature being between 25-30 ° C. The water hyacinth (*Eichhornia Crassipes*) enjoys increased attention due to the contribution in the production of biogas, bioethanol, water purification, biofertilizer, compost, mulch. Thanks to its high nutritional value, water hyacinth (especially leaves) can be used as food for fish and animals. Because hyacinth roots and stems are not considered animal feed, they can be used as biofuel to provide electricity or heat, thus increasing the economic and environmental benefits (Gaurav G.K et al., 2020; Ajithram A. et al., 2021; Yongming D. et al., 2020).

Figure 1. Utilization of the water hyacinth

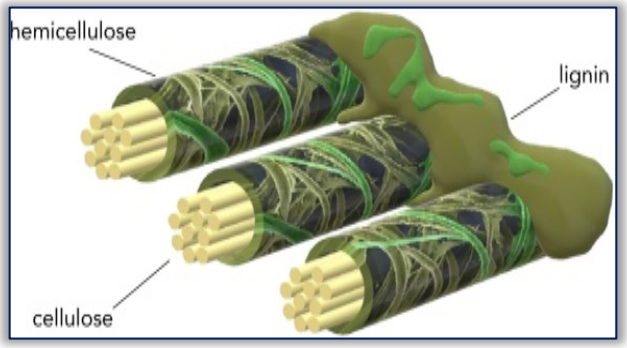

Figure 2. The structure of lignocellulosic biomass (Tursi et al., 2019)

2. BIOMASS FROM THE WATER HYACINTH

As a renewable source, biomass mainly contains cellulose, hemicellulose and lignin, with slight

variations depending on the biomass (Keche A. J. et al., 2015). The composition of the dried biomass from the water hyacinth was analyzed and the results show that the stem has a higher amount of cellulose than the leaves. The content of hemicellulose and lignin was significantly higher in the leaves compared to the roots and stem. At the moisture content between the parts of the plant, no noticeable difference was observed (Kiplangat R. et al., 2019).

Table 1. Element composition of water hyacinth aquatic plant (Ajithram et al., 2020)

Element composition	Percentage (%)
Carbon (C)	40-42.5
Oxygen (0)	27-29
Nitrogen (N)	1.2-4.6
Hydrogen (H)	5.2-6.5

The development of new energy technologies is needed to transform blocked sugars such as cellulose, hemicellulose, into high-yield ethanol and advances in pretreatment technologies (Nenciu F. et al., 2020).

3. BIOENERGY

The results of scientific research on biomass exploitation have contributed to the development of techniques capable of producing liquid biofuels, electricity and heat in the most economical and non-polluting way possible (Tursi et al., 2019). To reduce fossil fuel consumption, renewable energy sources are becoming an important alternative. The discovery of a sustainable production of renewable and cheap fuels has triggered an assiduous search for new sources, bioethanol being a biofuel with the greatest potential (Miranda A. F. et al., 2016; Foday-Junior E.H. et al., 2019). Although it is considered an invasive aquatic plant, the water hyacinth has an increased energy efficiency, being a renewable source with a rapid development.

— Bioethanol

Bioethanol is a biofuel obtained from biomass, whose importance is growing due to the depletion of non-renewable fuels. The production of bioethanol from the water hyacinth involves 3 stages of treatment, chemical reaction and fermentation (Dwivedi M. et al., 2018). Research has shown that pretreatment of water hyacinth, especially combined hyacinth, helps to obtain larger amounts of biofuel. In figure 3 shows the varied production of bioethanol according to the combined pre-treatment method applied to the water hyacinth (Zhang Q. et al., 2017).

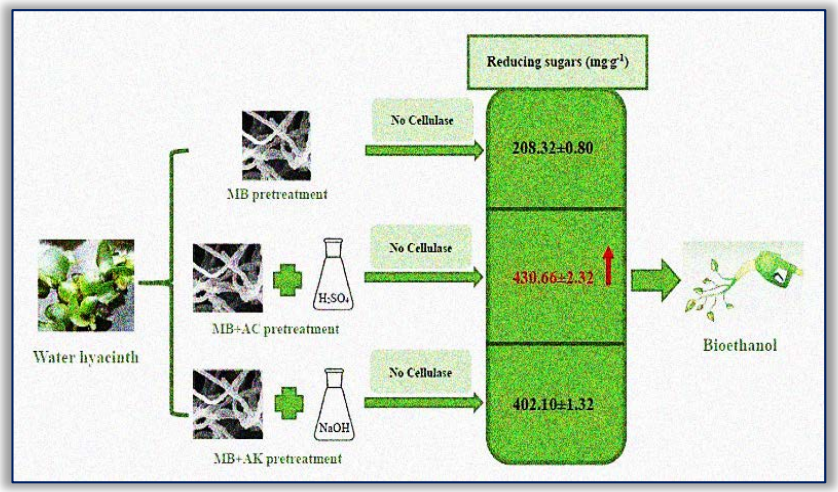

Figure 3. Obtaining various amounts of bioethanol by combined pretreatment of water hyacinth, MB: microbial pretreatment; MB+AC: microbial-dilute acid pretreatment; MB+AK: microbial-dilute alkaline pretreatment (Zhang Q. et al., 2017).

Hyacinth water has been studied as a raw material for the production of bioethanol. After pretreatment with hyperthermal acid (HT) hydrolysis, various enzymes were used to produce more glucose and xylose. The obtained results indicate that the biomass in the water hyacinth is suitable for the production of bioethanol (Sunwoo I.Y. et al., 2019). Based on the results obtained, it was found that during fermentation, a higher concentration of sugar helps to obtain a higher amount of bioethanol (Rezania S. et al., 2017).

To obtain bioethanol, the potential of floating macrophytes, water salad and water hyacinth was investigated. For the feasibility of biological pretreatment on the two aquatic plants, white rot fungi were used by monitoring the biodegradation of lignin and

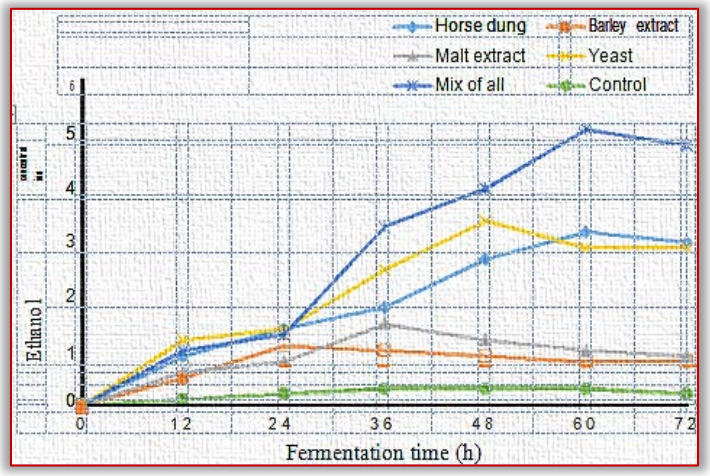

Figure 4. Ethanol production from water hyacinth using different types of enhancers (Rezania S. et al., 2017)

hemicellulose, and for fermentation, different concentrations of yeast were used. The results show that water hyacinth is more feasible for biodegradation of lignin and hemicellulose compared to water salad (Foday-Junior E. H. et al., 2019).

— Biodiesel

Ecological diesel - biodiesel is a biofuel with identical characteristics to diesel, which is obtained by the transesterification of vegetable oils (https://biodiesel.webgarden.ro/). For biodiesel production, water hyacinth biomass oil was analyzed. The resulting biodiesel was measured using a measuring cylinder. The main steps for the production of biofuel and other active ingredients from the water hyacinth are shown in figure 5 (Shanab S.M.M. et al., 2016).

It was examined to obtain biodiesel from water hyacinth, which was injected into the engine together with HHO (oxyhydrogen - hydrogen gas mixture - oxygen in a ratio of 2: 1). The maximum biodiesel yield of 87% was obtained at 1% KOH (Rahman M. A. et al., 2021).

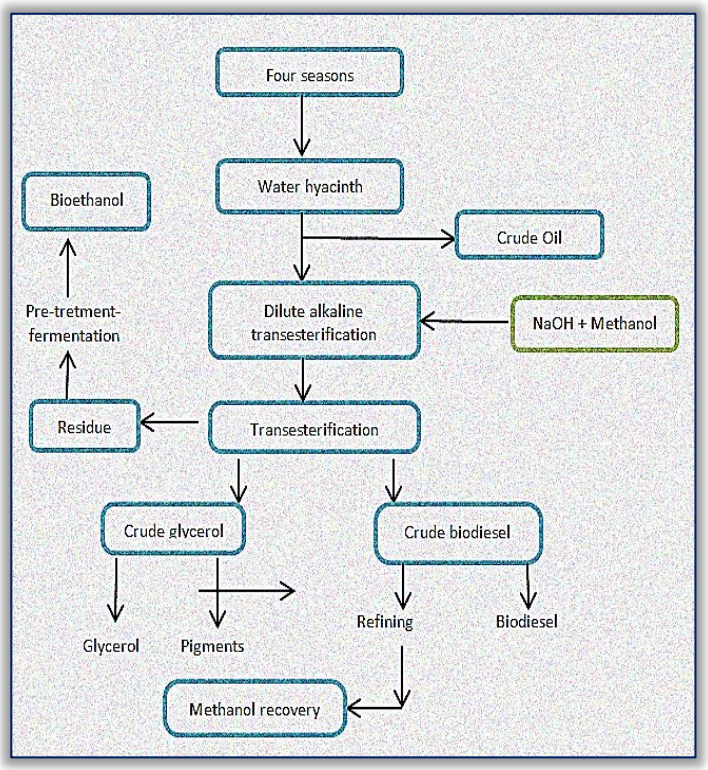

Figure 5. Diagrams illustrating the main steps for the production of biofuel and other active ingredients from Water hyacinth (Shanab et al., 2016)

— Biochar

Biochar is a carbonized biomass from sustainable natural resources or agricultural waste. (https://bestoncompany.com). The advantages of converting water hyacinth into biochar are described in the literature as illustrated in figure 6 (Gaurav G.K. et al., 2020).

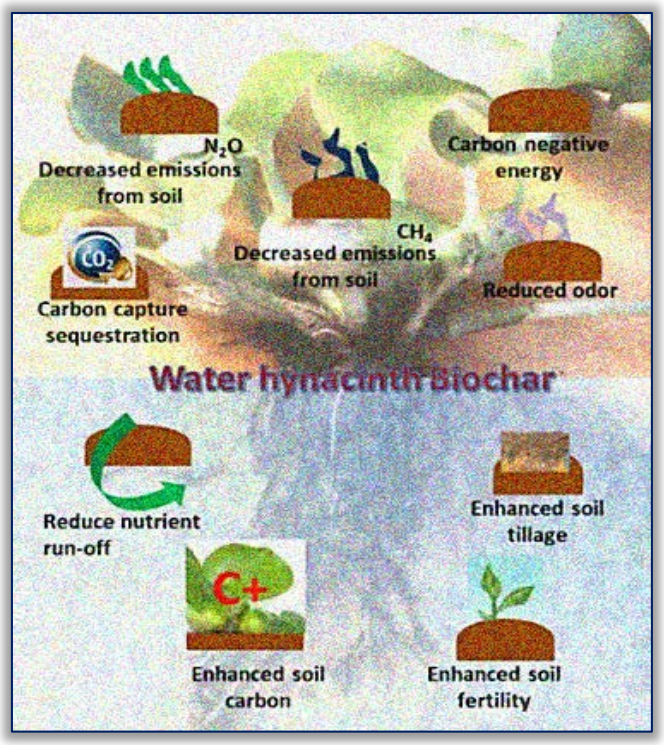

Figure 6. Benefits and utilization of Water Hyacinth biochar (Gaurav G.K. et al., 2020)

— Biogas

Biogas is a mixture of gases formed by the anaerobic fermentation of organic materials by methanogenic microorganisms.

Hyacinth has a real potential for biogas production. There have been several reports of the yield of floating macrophyte as a raw material for biogas assembly(Dwivedi M. et al., 2018).

The potential of the mixture of water hyacinth and cow dung biomass in biogas production was evaluated. The ratio of the two materials was 3: 1. The study shows a higher yield of biogas from the mixture of hyacinth and cow dung compared to cow dung. In conclusion, water hyacinth is a good raw material that can be used as a source of renewable energy.

Figure 7 illustrates the biogas production process and figure 8 the results of the research are presented on a daily basis (Njogu P. et al., 2015).

Also, the scientists investigated the production of biogas from the co-digestion of water hyacinth and cow dung waste. After 21 days, the resulting biogas was analyzed. The percentage composition of the biogas produced shows that methane gas (CH4) has 56.4%, carbon dioxide (CO2) is 35% and nitrogen (N2) is 6.9%. It turned out that the optimal production results depending on the temperature, pH and the design of the digester (Uche A. M. et al., 2020).

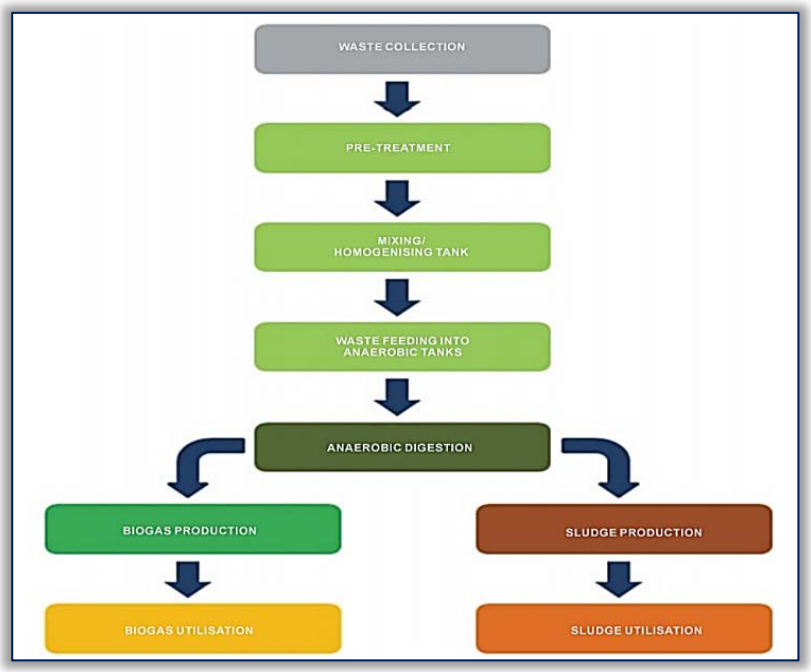

Figure 7. Biogas production process (Njogu P. et al., 2015)

4. PHYTOREMEDIATION

— Wastewater treatment

In the literature was evaluated the potential of water hyacinths in phyto-remediation of wastewater. The treatment was applied continuously for 30 days. The physico-chemical properties of the treated wastewater (water temperature, pH, total dissolved solids, turbidity, chemical oxygen demand) and physical characteristics of the water hyacinths were determined. The results proved the real potential of the water hyacinth in phyto-remediation of wastewater. In figure 9 an experimental installation for wastewater treatment is presented (Rajnikant P. et al., 2021).

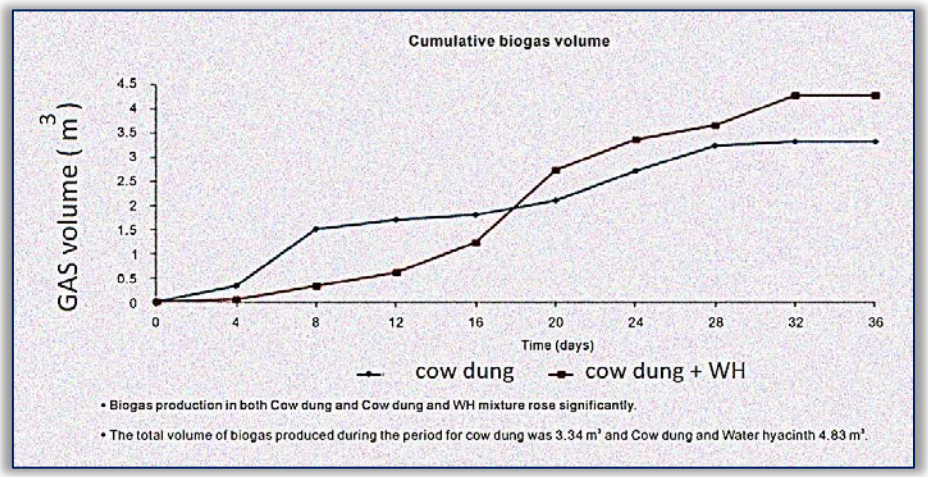

Figure 8. Biogas production with time (days) (Njogu P.et al., 2015)

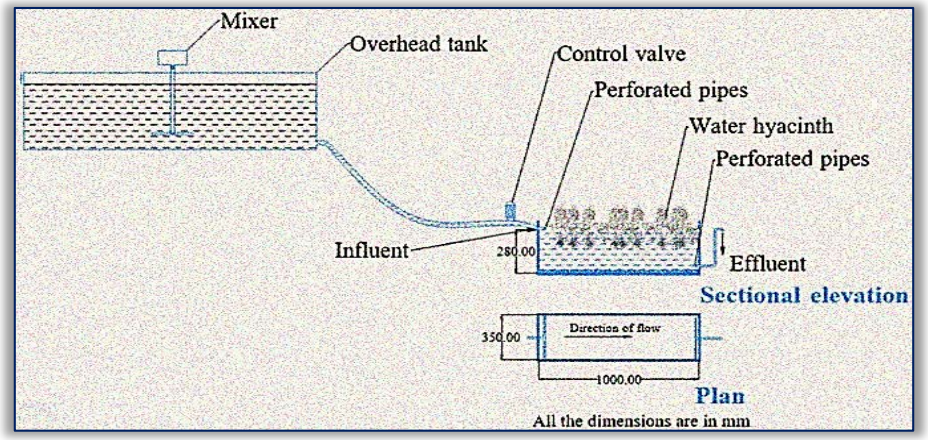

Figure 9. Sectional elevation and plan view of the experimental setup for greywater treatment (Rajnikant P. et al., 2021).

— Removal of heavy metals from wastewater

Reducing the spread of heavy metals in polluted waters is important because they are toxic and have negative effects on the environment and human health. Aquatic plants can be exploited to prevent the dispersion of heavy metals such as (Cd,, Ag, Pb, Sb, Zn, Sn and Cu) and to remedy contaminated areas without disturbing the environment too much. The results of research conducted in China shows that water hyacinth has a special ability to accumulate heavy metals (non-selective absorption), but also the power to increase absorption and their relocation to more contaminated places, indicating its ability to remove heavy metals from water. Figure 10 shows another use of the water hyacinth was presented, namely, the supply of energy for birds and animals (Yongming et al., 2020).

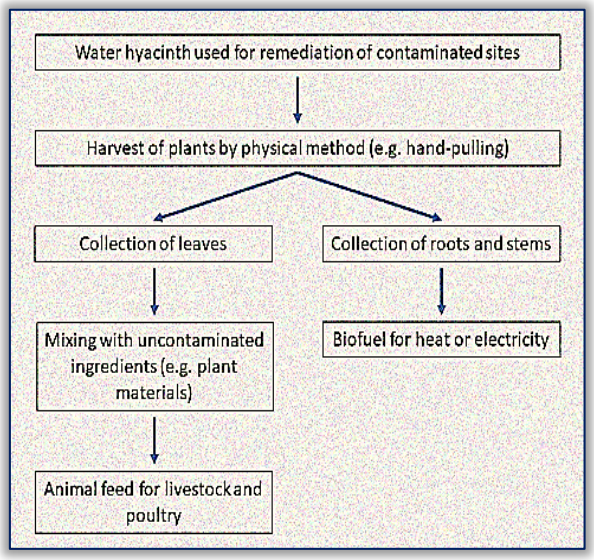

Figure 10. The proposed treatment for the harvested water hyacinth, which has been used for remediation of contaminated sites (Yongming D. et al., 2020)

The researchers examined the Cd sorption dynamics of biochar-alginate produced from water hyacinth. The highest Cd sorption was achieved at a temperature of 37 ° C and a pH of 6. The results obtained highlight the potential of biocar-alginate capsules derived from water hyacinth to remove Cd from wastewater (Cenwei L. et al., 2020).

5. BIOFERTILIZER

— Compost

Compost is partially decomposed plant debris and can be used as fertilizer. In its final state of decomposition it is called humus or mulch.

In addition to optimizing soil fertility and increasing its organic matter content, and compost helps reduce pollution from petroleum products. Figure 11 shows the flow of the composting process (Udume O.A. et al., 2021).

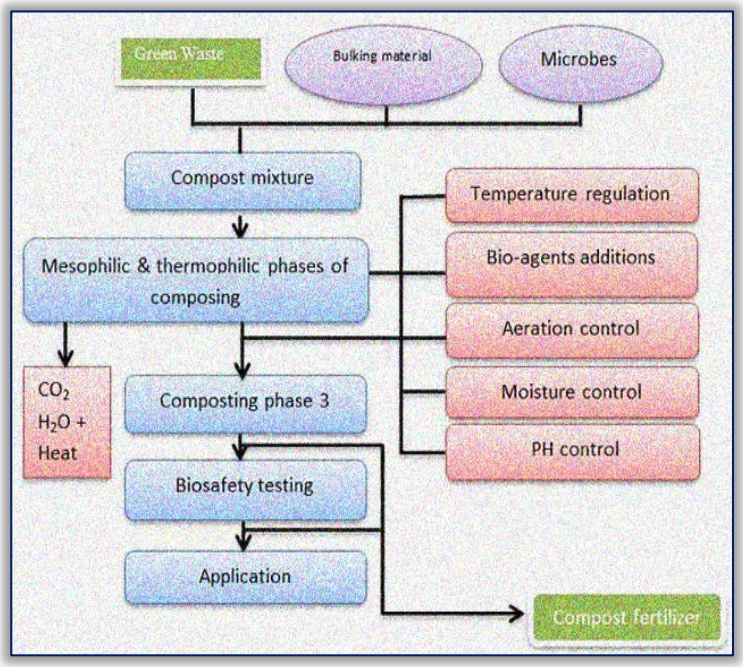

Figure 11. The composting process flow diagram (Udume O.A. et al., 2021)

The researchers investigated the contribution of water hyacinth in the production of compost and paper. The properties of the compost were tested following different methods, such as: wet digestion, flame spectrophotometry methods and different acids. The results suggest that water hyacinth biomass can be used as a raw material to obtain handmade paper, while the by-product of the process can be used to increase the nutritional quality of the compost (NazrulIslam M. et al., 2021).

For cultivating mushrooms (Pleurotus eous) water hyacinth was studied as an alternative substrate. The applied compost was composed of combinations of water hyacinth biomass, vegetable residues of rice, water hyacinth biomass and vegetable residues of rice. From the analysis of the data it results that by applying the water hyacinth substrate, the mushroom production increased considerably (810 g / 1 kg / dry. Wt.) Followed by the vegetable residues of rice. The water hyacinth substrate alone gave the lowest yield (Shirmila J.G. et al., 2018).

Due to the content of nitrogen (N), phosphorus (P) and potassium (K), water hyacinth-based compost can increase crop production. The researchers used field experiments and five treatments: water hyacinth compost obtained by adding cattle manure (WH + CM), bird manure (WH + PM), molasses (WH + MO), water hyacinth alone (WH alone) and control. The WH + PM compost formula applied to 3 t ha-1 was the most effective, as shown in table 2 (Dennis B. et al., 2018).

To increase soil quality, the potential of water hyacinth compost was investigated. Four different water hyacinth biomass-composting treatments were applied (H control only, H + cattle manure, H + Micro-organisms- EM, H + molasses).The results of the application of the 4 treatments show us that the water hyacinth has the ability to improve the soil by providing the necessary nutrients (P, K) and stabilizing the pH (Muoma J., 2016).

Table 2. The effect of water hyacinth-based composts on maize yield

	Rates (t ha^{-1})	Grain yield (t ha^{-1})	Harvest index	N_{AE} (kg kg^{-1})
Control	0	4.4	0.45	
WH+PM	3	6.5	0.47	25.3
WH+MO	3	6.5	0.42	42.6
WH+CM	3	6.3	0.43	29.8
WH alone	3	6.0	0.39	41.5
WH+CM	6	6.8	0.45	19.7
WH+MO	6	6.6	0.42	19.0
WH alone	6	6.1	0.42	20.8
WH+PM	6	5.8	0.41	11.0
LSD		1.1		19.4
CV (%)		25.7		77.1

Key: NAE = agronomic nitrogen efficiency; WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water (Dennis B. et al., 2018).

— Mulch

The word mulch was derived from the german word molsch which means "easily degraded", and mulching is the method of spreading various materials on the soil surface to minimize moisture loss, limit weed development and increase crop production (Kader M.A. et al., 2019).

To find out the application efficiency of water hyacinth mulch, rice straw and banana peel, various tests were applied, such as chemical analysis of organic mulch sheet and tensile strength. The obtained results show that the organic mulch with the strongest tensile strength was during the treatment with 60% water hyacinth, 20% rice straw and 20% banana pseudostem, reaching 3.28 N / m2 (Aniek I. et al., 2018).

Another experiment was conducted by researchers in India on a rice crop. The crop was divided into plots that were treated with three different forms of water hyacinth mulch, and the mulch-free served as a control. The different forms of water hyacinths, ie green foliage, compost and vermicompost were mulched at the rate of 5t / ha. Fresh green foliage had a higher amount of carbon (C), a total content of N and K compared to composts prepared from water hyacinths. However, the P concentration was higher in the vermicompost. The C / N ratio was higher in the green leaf (24.92), which decreased substantially when composted, as well as the content of cellulose, hemicellulose and lignin. However, they significantly decomposed after composting and even further (approx. 50%) in the vermicomposting process (Balasubramaniane D. et al., 2013).

In Bangladesh, to evaluate the effect of a different number of hyacinths as mulch on potatoes and tomatoes, research was conducted over two years (2015-2016). The changes in the different parameters influenced by the different quantities of mulch as shown in tables 3 and 4 were followed (Bhowmik S.K. et al., 2019).

Table 3. The effect of different numbers of hyacinths as mulch on the yield and yielding characteristics of the potato in both years

Treatment	Plant height (cm)	Nr. Stem	Nr. of tubers	Individual weight of the tuber (g)	Yield (t / ha)
T_1= No mulch	34.10	4.11	5.86	259.4	18.58
T_2 = 56 t ha^{-1}	40.72	4.67	6.65	327.3	22.23
T_3 = 62 t ha^{-1}	43.89	4.88	7.05	369.7	24.13
T_4 = 68 t ha^{-1}	45.67	5.04	7.87	406.1	26.46

Table 4. The effect of different numbers of hyacinths as mulch on yield and the yield-contributing characters of tomatoes

Treatment	Plant height (cm)	Nr. of fruits	Individual weight of fruit (g)	Yield (t / ha)
T_1= No mulch	103.68	21.10	73.39	55.13
T_2 = 56 t ha^{-1}	108.05	24.63	75.06	62.72
T_3 = 62 t ha^{-1}	108.93	26.72	75.97	65.85
T_4 = 68 t ha^{-1}	109.41	28.15	76.14	67.29

These results showed that the addition of larger quantities of water hyacinth mulch in potato and tomato crops, helps to control and preserve soil moisture and higher yields. The maximum total production obtained increased by 22.74% compared to the plot where no mulch was used (Bhowmik S.K. et al., 2019).

6. ANIMAL FOOD

The widespread use of hyacinth biomass as animal feed is appreciated in commercial production, as animal feed always brings financial benefits to the market. Hyacinths biomass has been used as animal feed or leaf protein for sheep, cattle, pigs, geese, etc. (either in fresh form or in silo form). The literature shows that hyacinth biomass has a high potential for animal feed, based on the nutritional value of dehydrated hyacinth biomass (Bai Y.F. et al., 2017).

The effects of dietary administration of aquatic extract (WLEA) and alcohol extract (WLEM) from water hyacinth were monitored as an immunostimulant on non-specific immune parameters, antioxidant defense and resistance against Streptococcus iniae in rainbow trout (Oncorissynch) chickens. The results of the test showed

that the administration of diets supplemented with water hyacinth extract (WLE) significantly increased the resistance to trout (P <0.05), figure 12.

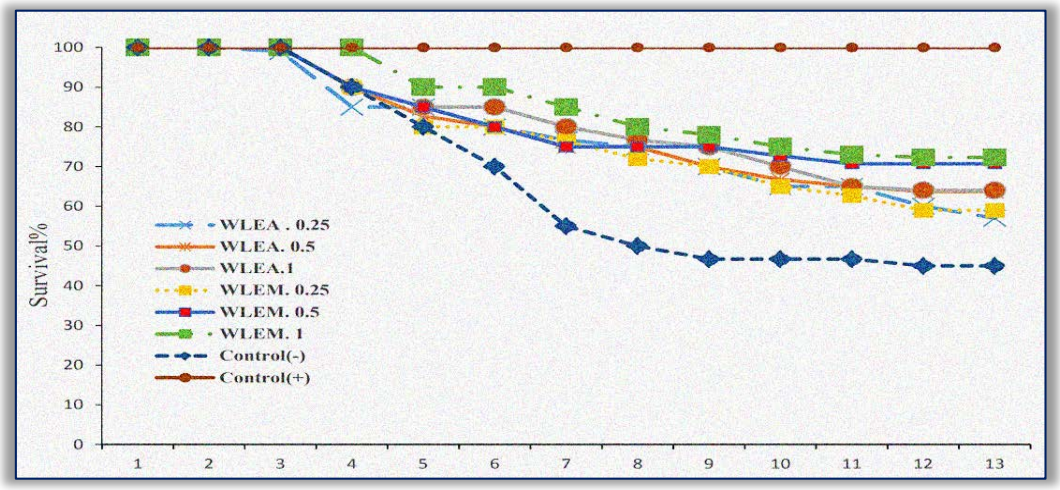

Figure 12. Survival rates (%) of rainbow trout fingerlings fed with WLE supplemented diet at different levels during 14 days post challenge with *Streptococcus iniae* (Rufchaei R. et al., 2019).

The hydromethanol extract from aquatic plants was more effective than the aqueous one in disease resistance, the development of antioxidant and nonspecific immune factors, which means that diets supplemented by WLEM and WLEA confirmed the response to dose and time as shown in (Rufchaei R. et al., 2019).

7. CONCLUSIONS

Due to the increased consumption of non-renewable resources, it is vital to discover as many renewable resources as possible, in the context of sustainable agriculture. One of the best known renewable sources is biomass. An important source of biomass comes from agriculture.

Despite the fact that aquatic plants are known as invasive plants, their biomass has many uses. The water hyacinth also belongs to this category. The floating macrophyte, water hyacinth has a real potential in obtaining biofuels, in treating wastewater, as fertilizer and feed for animals and fish.

This paper described the hyacinth of water, as a renewable energy resource, with its many uses in sustainable agriculture.

All the results obtained from the analysis of water hyacinth, encourage the deepening of future research to discover new applicability of the aquatic plant.

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References

[1] Ajithram A., Winowlin Jappes J.T. and Brintha N.C., (2020), Investigation on utilization of water hyacinth aquatic plants towards various bio products – Survey, Materials Today: Proceedings
[2] Ajithram A., Winowlin Jappes J.T., Brintha N.C., (2021), Water hyacinth (Eichhornia crassipes) natural composite extraction methods and properties – A review, Materials Today: Proceedings, 45, Part 2, 1626-1632;
[3] Antal J., Grasselli G., (2007), Biomass Utilisation for Sustainable Spatial Development in Erdispuszták Territory, VI. Alps-Adria Scientific Workshop Obervellach,185-188
[4] Bai Y.F., Guo J.Y., (2017), Utilization of Water Hyacinth Biomass for Animal Feed, Book Water Hyacinth Environmental Challenges, Management and Utilization (1);
[5] Balasubramaniane D. et al., (2013), Water hyacinth [Eichhornia crassipes (Mart.) Solms.] engineered soilnutrient availability in a low-land rain-fed rice farming system ofnorth-east India, Ecological Engineering 58, pp 3– 12;
[6] Bhowmik S. K. et al., (2019), Effect Of Different Amount Of water hyacinth As Mulch On Potato And Tomato At The Saline Soil Of Noakhali, Abc Research Alert Vol 7, Number 3;
[7] Dennis B. et al., (2018), Agronomic effectiveness of water hyacinth-based composts, African Journal of Agricultural Research, 13(39), 2055-2062
[8] Dwivedi M., Dwivedi A.K., (2018), Valuable Product from Water Hyacinth – Review Paper, International Research Journal of Engineering and Technology (IRJET), 5 ,Issue 3

[9] Foday-Junior E.H., Mohd Fadhil M.D., Koroma A. K., (2019), Bioethanol from water hyacinth by white rot fungi in biodegradation, International Journal of Life Sciences (Amravati), 7 (1), 21-32, ref.22
[10] Gaurav G.K. et al. , (2020), Water hyacinth as a biomass: A review, Journal of Cleaner Production
[11] Goldemberg J., Coelho S.T., (2004), Renewable energy—traditional biomass vs. modern biomass, Energy Policy, 32(6), 711-714;
[12] Iriany A., Chanan M., Djoyowasito G., (2018), Organic mulch sheet formulation as an effort to help plants adapt to climate change, International Journal of Recycling of Organic Waste in Agriculture, 7:41–47
[13] Kader M.A et al., (2019), Mulching as a technique of water economy in dry agriculture. National Research Centre Bulletin 43:1–6;
[14] Keche A.J., Gaddale A.P.R., Tated R.G., (2015), A.P.R. & Tated, R.G. Simulation of biomass gasification in downdraft gasifier for different biomass fuels using ASPEN PLUS. Clean Techn Environ Policy 17, 465–473
[15] Liu C. et al., (2020), Removal of Cadmium (II) using water hyacinth (Eichhornia crassipes) biochar alginate beads in aqueous solutions, Environmental Pollution, 264, 114785;
[16] Marsanich A., (2003), Biomass. In: Rennings K., Zwick T. (eds) Employment Impacts of Cleaner Production. ZEW Economic Studies (Publication Series of the Centre for European Economic Research (ZEW), Mannheim, Germany), vol 21. Physica, Heidelberg
[17] Miranda A.F. et al., (2016), Aquatic plant Azolla as the universal feedstock for biofuel production. Biotechnol Biofuels , 9, 221.
[18] Muoma J., (2016), Production of Organic Compost from water hyacinth (Eichhornia crassipes [Mart.] Solms) in the Lake Victoria Basin: A Lake Victoria Research Initiative (VicRes), Research & Reviews: Journal of Agriculture and Allied Sciences, vol. 5, ,Issue 2,
[19] NazrullIslam M. et al., (2021), Water hyacinth (Eichhornia crassipes (Mart.) Solms.) as an alternative raw material for the production of bio-compost and handmade paper, Journal of Environmental Management, 294, 113036;
[20] Nenciu F., Găgeanu G., Matache M.G. et al., (2020), Simplified Method for Producing Bioethanol from Jerusalem Artichoke Tubers, Research on the Influence of Climatic Conditions, Soil and Processing Methods for the Production of Biofuels, ISB INMA TEH
[21] Njogu P., Kinyua R., Muthoni P. et al., (2015), Biogas Production Using Water Hyacinth (Eicchornia crassipes) for Electricity Generation in Kenya. Energy and Power Engineering, 7, 209-216
[22] Prasad R. et al., (2021), Preliminary study on greywater treatment using water hyacinth, Applied Water Science, 11,88
[23] Rahman M.A. and Aziz M. A., (2021), Biodiesel from water hyacinth biomass and its influence on CI engine performance, emission, combustion and heat loss characteristics with the induction of hydrox, Energy, 224;
[24] Rezania S., Din M.F.M.,Taib S.M. et al., (2017), Ethanol Production from water hyacinth (Eichhornia crassipes) Using Various Types of Enhancers Based on the Consumable Sugars, Waste Biomass Valor, 9, 939–946
[25] Rop K. et al., (2019), Biodegradable water hyacinth cellulose-graftpoly(ammonium acrylate-coacrylic acid) polymer hydrogel for potential agricultural application, Heliyon, 5 , e01416
[26] Rufchaei R., Mirvaghefi A., Hoseinifar S.H. et al., (2019), Effects of dietary administration of water hyacinth (Eichhornia crassipes) leaves extracts on innate immune parameters, antioxidant defense and disease resistance in rainbow trout (Oncorhynchus mykiss), Aquaculture, doi: https://doi.org/10.1016/j.aquaculture.2019.734533;
[27] Shanab S.M.M., Hanafy E. A., Shalaby E. A., (2016), water hyacinth as Non-edible Source for Biofuel Production, Waste Biomass Valor
[28] Shirmila J.G. et al., (2018), Bioconversion of water hyacinth as an alternate substrate for mushroom (Pleurotus eous) cultivation, Trends in Biosciences, 11(7), 1447-1451 ref.7;
[29] Sunwoo I.Y., Kwon J. E., Nguyen T. H. et al., (2019), Ethanol production from water hyacinth (Eichhornia crassipes) hydrolysate by hyper thermal acid hydrolysis, enzymatic saccharification and yeasts adapted to high concentration of xylose, Bioprocess and Biosystems Engineering,
[30] Tursi A., (2019), A review on biomass: importance, chemistry, classification, and conversion. Biofuel Research Journal, 22, 962-979
[31] Uche A.M. et al., (2020), Design and construction of fixed dome digester for biogas production using cow dung and water hyacinth, African Journal of Environmental Science and Technology, 14(1), 15-25,
[32] Udume O.A., Abu G.O. and Stanley H.O., (2021) Composting A Low-cost Biotechnological Approach to Ameliorating Macrophyte Nuisance in Fresh Waters, Journal of Agriculture and Ecology Research International, 22(3), 47-71, JAERI.68979
[33] Yongming D. et al., (2020), Accumulation and translocation of heavy metals in water hyacinth: Maximising the use of green resources to remediate sites impacted by e-waste recycling activities, Ecological Indicators, 115, 106384;
[34] Zhang Q., Wei Y., Han H. et al., (2017), Enhancing bioethanol production from water hyacinth by new combined pretreatment methods, Bioresource Technology;
[35] https://bestoncompany.com;
[36] https://biodiesel.webgarden.ro/.


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