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Assessing the Ecological Potential of Plant Based Biochar (*Nypa fruticans* Wurmb and *Eichhornia* crassipes (Mart) Solms) As Briquettes for Sustainable Wetland Ecosystem Restoration

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Abstract

Nearly half the world's population is dependent on wood as their primary source of energy. Consequently, deforestation and ecosystem degradation has become increasingly prevalent in many regions of the developing world, therefore is an urgent need to improve the combustion efficiency of domestic source of fuel or/ and find alternative fuel sources. This investigation was aimed at exploring the energy production potential of *Eichhornia crassipes* (Mart) Solms and Nypa fruticans Wurmb as alternative source of waste utilization; with the objectives of waste to wealth conversion of loose biomass to biochar as a sustainable approach to aquatic weed management, and evaluating their potential as source of biofuel and combustion characteristic in relation to environmental consequences. Standard procedures of sample collection, processing by drying, carbonization, and densification methods and data analyses by ANOVA were adapted. Result indicated *E. crassipes* with significantly higher moisture (28.20+1.51), ash (54.55+3.48), and volatile matter (8.30+1.34) than *N. fruticans* which recorded significantly faster ignition time (19.00+2.65), higher fixed carbon (54.39+5.76), water boiling rate (740.00+69.74),bulk density (0.002+0.00),shatter resistance (94.83+2.63), heat of combustion (3196.55+230.55) and burning time (13480.00+570.26). Conclusively, the low moisture content of the produced briquette, the low volatile matter content of the briquettes are affirmation that they are environmentally friendly hence harmful substances like carbon and sulphur are not released into the ecosystem and with the proficiency in thermal capacity the ecosystem balance can be checked with the use of briquettes from these plant species.

Keywords: Proximate Analysis; Thermal Analysis; Carbonization; Densification; Biofuel

Introduction

Historically the development of Biochar is evolving in light of diverse ecological scenarios particularly in areas of environmental alterations and restoration options [1]. It is one of humanity's earliest sources of energy from biomass renewable energy source particularly in rural areas where it is often the only accessible and affordable source [2]. Biochar is a carbon rich product of biomass, such as wood, manure or leaves when heated in a closed container with little or no available air [3]. In other words it is produced by thermal decomposition of organic material under limited supply of oxygen and at relatively low temperature (<700°C) in a process termed Pyrolysis [4]. Similarly, from the International Biochar Initiative (IBI) such product is seen as the solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Such thermal decomposition is usually on different types of organic feedstock of biomass materials (such as plantations that produce energy crops, natural vegetable growth, organic wastes and residues (animal wastes, forest residue, agricultural residue, etc.) in varying pyrolysis degrees [5]. Carbonized organic matter can essentially have different physical and chemical properties based on the technology (e.g. slow pyrolysis, intermediate pyrolysis, fast pyrolysis, gasification, hydrothermal carbonization (HTC) or flash carbonization) used for its production [6]. Pyrolysis temperature can be distinguished by the residence time, pyrolic temperature of the material (slow and fast pyrolysis), pressure, size of absorbent, the heating rate and method and carbonization process [7-9].

Biochar from a chemical point of view other than a productive point is much more difficult to elucidate due to the wide variety of biomass and charring conditions used for its production. They are made from biomass that has different chemical and physical properties which are important in the pyrolysis process especially in the proximate analysis (moisture content, ash and fixed carbon and volatile matter), calorific value, percentage lignin, cellulose and hemicellulose percentage, composition of inorganic substance, bulk, true density and particle size [10,11]. Although carbon is the major constituent of carbonaceous materials the exact composition and physical properties of biochar depends on the production material and the conditions in which it was produced. Statutorily it has a high carbon content comprised of aromatic compounds with six C atoms linked together with O or H. However, elemental analysis has shown that biochar primarily has five elements viz: hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and carbon (C) which may vary in percentages based on the characteristic of the conversion process (temperature) and type of the biomass feedstock [12-14].

Over the last few decades, biochar has attracted global attention due to its high potential multiplier effect in diverse endeavours of human existence, in light of which several studies have reported its potential in soil amendment in terms of soil fertility [15]; agricultural productivity [16]; heavy metal sequestration [17]; soil pH regulation [18]; enhanced soil microbial activity [19]; enhanced cation exchange capacity [20]; improved soil health in terms of decrease in bulk density, increased porosity and water holding capacity [13,21]; waste management in terms of heavy metal, metalloids, contaminants and pollutants removal [22-24] and environmental remediation. Other potential entails wastewater treatment, water purification, power generation, energy storage, carbon sequestration, and building sector, etc. [25,22,26-30]; as a catalyst for tar removal from syngas and production of biofuel and soil conditioner [31].

However, the present study goes beyond the aforementioned qualities and potentials of biochar, as it focuses on the energy production ability of two alien invasive plant species biochar as briquettes to help control their infestation in the aquatic ecosystem. Raw materials that can substitute fossil energy as source of fuel are biomass and biofuel [32]. One of the ways of obtaining biofuel is by biomass briquetting of alien invasive species such as water hyacinth (*Eichhornia crassipes*) and Nypa palm (*Nypa fruticans*). Of great importance, the replacement of energy sources with energy obtained from untapped biological sources would lower the carbon footprint and overall global pollution status; such energy from biomass materials offers the potential to reduce the greenhouse gas emissions from fossil fuels [33]; guarantee energy security and tackle environmental problems [34], and contributes to its efficient management and to developing rural areas economically [35]. The potential of using biomass in producing high energy concentrated fuels in the form of briquettes has been explored [36].

Water hyacinth by its growth pattern covers water surfaces with the consequences of impacting on sea route navigation and aquatic lives [37], while Nypa palm displaces traditional indigenous mangal species with serious ecological threat to mangrove biodiversity [38]. The United Nation (2000) attested that water hyacinth can never be eradicated; instead it is a situation that must be continually managed. This informed the bases for the initiation of this research with the aim of exploring the comparative advantage in the energy potential of *Eichhornia crassipes* and *Nypa fruticans* for briquette production as an alternative option to untapped waste utilization and eradication of alien species invasion, with the objectives of waste to wealth conversion of *Eichhornia crassipes* and *Nypa fruticans* to biochar as a sustainable approach for adequate aquatic weed management, unveiling an effective methods for converting Water hyacinth and Nypa palm biomass to briquettes and evaluating their role as source of biofuel.

This study is concerned at making an appropriate and efficient use of these invaders in energy briquetting which will serve as an alternative to local wood fuels, preventing deforestation, pollution by waste management and helps to control the influx of carbon into the atmosphere. Briquetting offers the opportunity of these biomass materials to have good characteristics and fuel properties. It serves as a good source of energy for local communities, stimulate a shift from petroleum products like, kerosene, coal, and diesel and reduce emission since the briquette is a carbon neutral source. This work therefore, will guarantee energy security, tackle environmental problems such as invasive alien species proliferation associated with Niger Delta wetlands and contributes to the development of littoral rural communities.

Materials and Methods

Description of Study Area, Location and Site

The study area is Rivers state located between long.6˚23 E and 7˚36′ E and lat. 4˚18′ N and 5˚45′ N of the equator (Figure 1). The State is surrounded by Imo River and Akwa-Ibom in the east, Bayelsa State in the west, Imo and Abia States in the North and Atlantic Ocean in the south. It is characterized by tropical rainforest and mangrove vegetation with a climatic condition variable rainfall ranging between 2,500 to 3,500 mm annually and relative humidity under the influence of latitudinal and seasonal variation, influence of the Atlantic Ocean, Mean maximum monthly temperature range of 28 to 33°C and minimum monthly temperature of 17°C and 24°C [39]. The study area is composed of 23 local council authorities including Opbo/Nkoro and Ahoada East study locations (Figure 4.1).

Figure 1: Rivers State Study Area Showing Ahoada East & Opobo/Nkoro Study Locations.

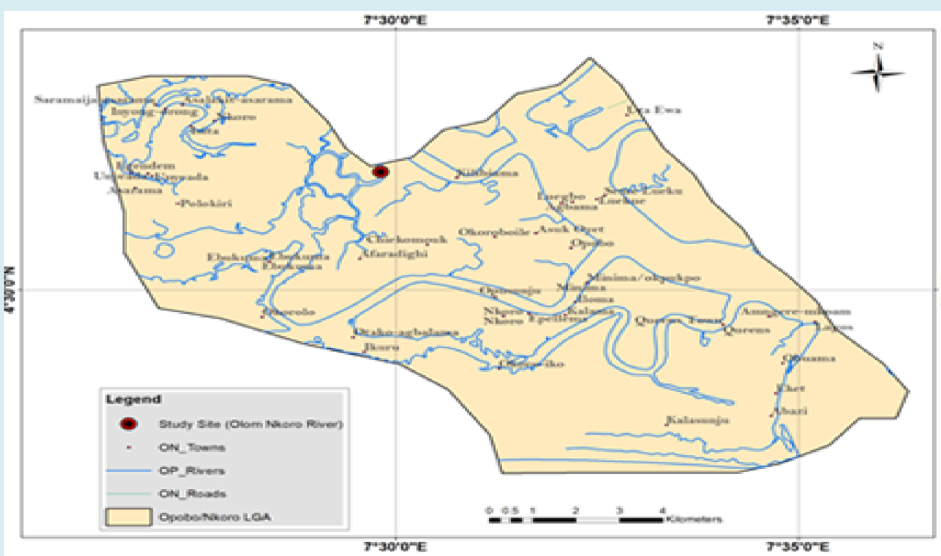

Figure 2: Opobo/Nkoro Study Loation Showing Study Site -Nkoro.

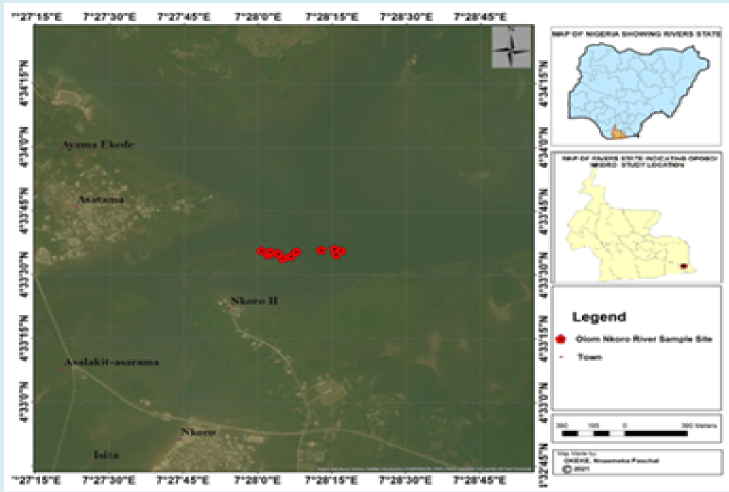

Figure 3: Nkoro Study Site Indicating Olom-Nkoro Sampled Site & Olom-Nkoro River Sampled Point.

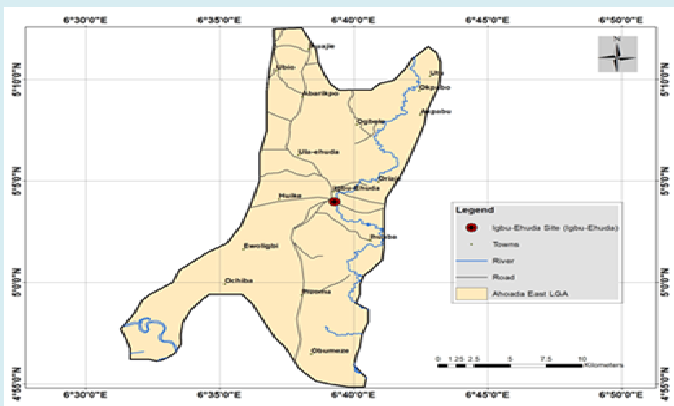

Figure 4: Ahoada East study location indicating Igbu-Ihunda study site.

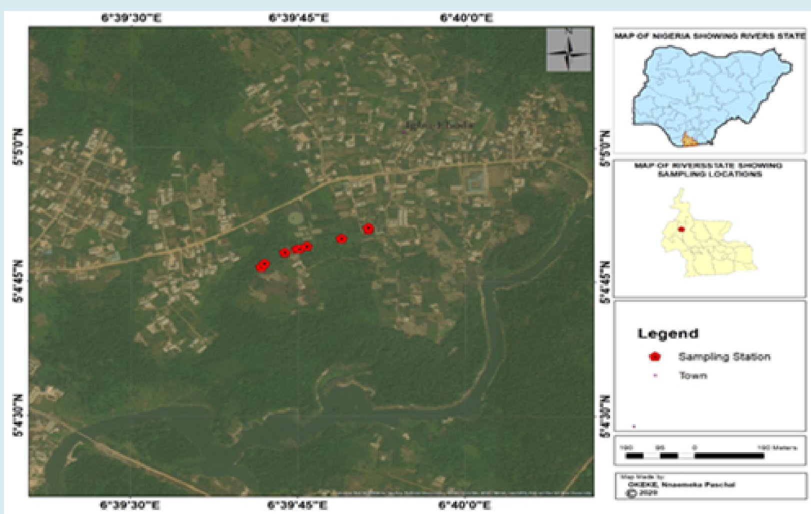

Figure 5: Igbu-Ehunda Study Sit Indicating Emene Oshi River Sampled Site.

The Opbo/Nkoro study location is situated at lat. 5°4′30″N and 4°5′0″N, Long. 6°39′30″E and 6°40′0″E, with constant varying climatic condition due to tidal influence and an average temperature of 25^{0}C and 79% humidity. This location is comprised of two major towns, viz: Opobo and the study site – Nkoro, (Figure 2) a littoral coastal town consisting of eight communities including the sample site – Olom-Nkoro (Figure 3) with diverse mangrove species being totally surrounded by saline water of a high tidal correlation with the plant species found in it and largely occupied by the invasive Nipa plant highly prolific in nature. The species encroaches the sampled point - the Olom-Nkoro River (Figure 4.3), a water body high in salinity thereby making the plant species halophytic. The site is largely invested with Nipa palm making it very distinctive; with a muddy flat black soil. It experience twice-daily flooding by ocean tide.

The Ahoada East study location is situated between lat. 5°4′30″N and 4°5′0″N, long.6^{0}39′30″E and 6^{0}40′0″E characterized by a tropical climatic temperature condition ranging 17^{0}C - 33^{0}C, with such a warm wet season and moist dry season. The study site is Igbu-Ihunda (Figure 4), a town known for its daily market activities in Ahoda East. The sampled site is Emene Oshi River (Figure 5), a fresh water habitat with high nutrient value making a luxuriant spontaneous growth of plant species that colonize the site. The water is of a low salt content and the soil is a fine sandy soil.

Biomass Species Sampling

The *Eichhornia crassipes* (Figure 6a) was collected by uprooting the sample from Emene Oshi River sampled site habitat at Igbu-Ehunda Study site in Ahoada East study location. This was done careful to ensure the entire biomass of the sample on fresh weight bases was maintained. The *Nypa fruticans* (Figure 4.6b) was collected from the Olom-Nkoro River sampled site at Nkoro II study site in Opobo / Nkoro study location using a machete to cut of mature bunch of fruit from the plant stand. The mature fruit were collected to reduce dispersion hence they can easily get loose from stand. The sampled site were validated using a hand - held Geographic Positioning System (GPS - *Garmmi Dakota 10 model*) for the georeferencing of the exact sampled point of the species in question (Table 1) and imagery production of the sampled sites (Figures 3 & 5) with the plant species biomass identified and recorded from the sampled sites.

Figure 6 a & b: Fresh Biomass Feedstock (A*) E. Crassipes* & (B) *N. Fruticans.*

***Eichhornia crassipes (*Mart) Solms**		
Lat.(North)	**Long. (East)**	**Alt.(ft)**
05°04’483”	006°39’440”	4
05°04’487”	006°39’451”	6
05°04’487”	006°39’453”	6
05°04’487”	006°39’453”	3
05°04’490”	006°39’460”	6
05°04’499”	006°39’491”	-8
05°04’509”	006°39’515”	4
05°04’511”	006°39’515”	11

05°04’467”	006°39’419”	3
05°04’471”	006°39’422”	7
***Nypa fruticans* Wrumb**		
04°33’357”	007°28’008”	5
04°33’347”	007°28’021”	9
04°33’349”	007°28’023”	9
04°33’354”	007°28’026”	4
04°33’350”	007°28’042”	1
04°33’339”	007°28’051”	6
04°33’343”	007°28’067”	3
04°33’354”	007°28’079”	1
04°33’355”	007°28’101”	0
04°33’358”	007°28’129”	3
04°33’361”	007°28’155”	4
04°33’348”	007°28’159”	10
04°33’357”	007°28’169”	10

Table 1: GPS Coordinates of Sampling Points for Biomass.

Processing of Sampled Biomass

Drying

The Nipa seeds were separated from the bunch of fruit with a cutlass. Initial moisture content of *Eichhornia crassipes* and *Nypa fruticans* seeds as collected were 85.16% and 72.2% wet basis (w.b), respectively. Both materials were then sun dried and subsequently oven dried to reduce the moisture content (Figure 1). The entire processing and analyses were carried out in Chemical Engineering Laboratory, University of Port Harcourt.

Figure 7 a & b: Dried biomass of feedstock (a) *Eichhornia crassipes* & (b) *Nypa fruticans* seeds.

Carbonization of Biomass to Biochar

The Carbonization of the dried Water hyacinth and Nipa was carried out using a muffled furnace (Carbolite Sheffield England LMF 4) which allows limited supply of air. Carbonization was done at 350^{0}C for two hours and allowed to cool at room temperature for three hours prior to briquette production. Upon removal of samples from the furnace, water was poured on it to arrest or prevent it from forming ash (Figure 2).

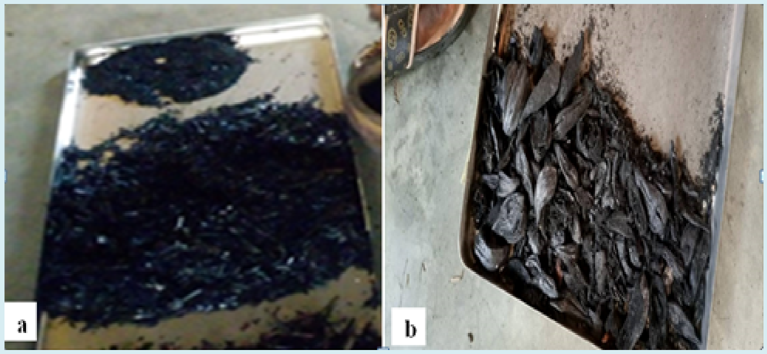

Figure 8 a& b: Carbonized biomass; (a) *E. crassipes* biochar & (b) *Nypa fruticans* biochar.

Briquette Production

The carbonized samples were crushed to have reduced particles using the crushing machine. Starch was used as the binder hence it is the most effective binding agent for briquette production. The binder was gelatinized using hot water and mixed properly with the crushed particles. The briquettes were formed in a cylindrical mold. The mold was filled with the mixture and densified under constant operating conditions (temperature of 28^{o}C) with a manually operated hydraulic piston press. After densification, the resultant briquettes were placed in an oven (Figure 3) and left to dry before testing for properties. Briquettes were made from each biochar sample (Figure 6 a&b) and with their initial densities measured.

Figure 9: Briquettes drying in an oven.

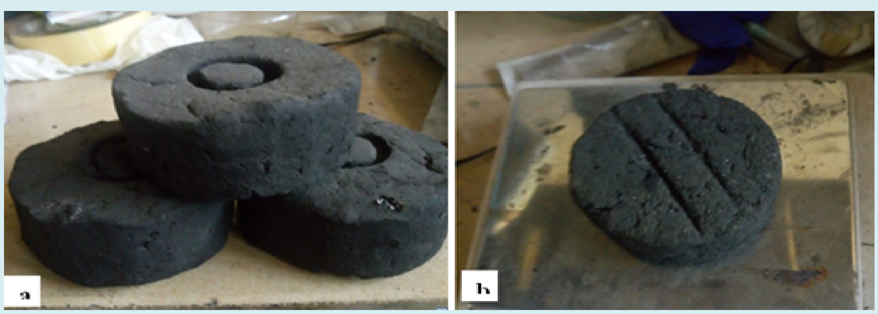

Figure 10 a & b: Biochar briquettes (a) *Eichhornia crassipes* & (b) *Nypa fruticans.*

Briquette Characterization

The briquette product were analysed for physical properties and characteristics to ascertain the environmental friendly suitability based on the following indices:

Determination of Proximate Analysis: ASTM defines proximate analysis as the determination by prescribed methods of moisture, volatile matter, ash and fixed carbon. The proximate analysis of Nipa and Water hyacinth was carried out following the procedures given below.

- **Moisture Content (MC)**

The moisture content was determined by oven dried method in accordance with ASTM D2444 [40]. The percentage moisture content was taken on wet basis and is calculated with the formula

$$\%MC\ (\text{wet basis}) = \frac{\text{Weight before-Weight after}}{\text{Weight before}}(g)\times 100$$

- **Volatile Matter (VM)**

The volatile matter was determined using the ASTM D3175-18 [41] method with the v calculation as follows

$$\text{Volatile matter }(\%)=\frac{\text{Weight of Volatile Matter}}{\text{Oven Dry weighy}}(g)\times 100$$

- **Ash Content (AC)**

The test method for ash content was the ASTM D3174-12 [42] and with the percentage ash content calculated as follows

$$\text{Ash content }(\%)=\frac{\text{Weight of Ash}}{\text{Weight of sample}}\times 100$$

- **Fixed Carbon Content (FC)**

This is the percentage of carbon available for char combustion. This is not equal to the Total amount of carbon in the Briquette. After the Ash was separated, what was left was carbon; percentage fixed carbon was calculated using the British Standard Method (BSI) [43].

% fixed carbon = 100% - (%Ash + %Moisture + %Volatiles)

Bulk Density Determination (BD): The density of the briquettes was determined in accordance with ASTM D2444-16 [44] method; and with the result extrapolated from the analysed data calculated as the ratio of the mass of the briquette to the volume of the briquette using formula below:

$$\rho b=\frac{M}{V}$$

Where ρb is the Bulk Density, M is the mass, and V is the particle volume

Determining of Shattering Index (SR): The durability of the Briquette was determined with the Shattering Index as adapted in ASTM D440-86 [45] following the formula below:

$$\text{Percentage Weight loss}=\frac{\text{Initial Weight before shatter-Weight after shattering}}{\text{Initial Weight of briquette before shattering}}$$

Shatter resistance = 100 – Percentage weight loss

Thermal Analysis:

- **Ignition Time: (IT)**

This is the average time taken to light the briquettes to get burning as adapted by Onuegbu et al. [46] with a known mass of dry briquette sample been clamped to a clamp stand then ignited with match stick. The time taken for a certain amount of the sample to be ignited is noted at the first appearance of visible ignition.

- **Burning Time (BT)**

This is the time taken for a complete unit of known mass to burn completely.

- **Burning Rate (BR)**

This is the rate of which specific mass is lost due to the combustion of the Briquette. It was determined by burning the briquette in a controlled environment. A known mass of the briquette was burned and time taken. A stopwatch was used for take timing and the briquette was burned until completely exhausted. The burning rate is the ratio of the mass of the fuel (Briquettes) burnt in grams to the time taken for it to burn in minutes as adapted in [46] and was calculated using the formula below:

$$\text{Burning rate}=\frac{\text{Mass of fuel consumed}}{\text{Total time taken (min)}}$$

- **Water Boiling Test (WBT)**

This is the function of the volatile matter and calorific value. It is the time taken by a briquette to boil a certain volume of water as adapted by Onuegbu et al. [46] with a beaker of water kept on the briquette and the briquette ignited. The time taken for the water to boil was taken. The specific fuel consumption indicate the ratio of the mass of fuel consumed (g) to the quantity of boiling water in liters.

Specific Heat of Combustion (SHC):

The energy content of the briquette is determined by adapting the bomb calorimeter method [47] and with the heat released being calculated as follows;

Specific heat= 0.35 [(147.6×FC) + (144×VM) + (%Ash)]

Data Analysis

Samples data were subjected to Analysis of Variance (ANOVA) and Fisher's Least Significance Difference (LSD) test to determine the significant difference between the various briquette characteristics. Descriptive statistics that includes mean and standard deviation of estimates was also used to describe the data, where the significant differences were encountered; the means were separated using Duncan Multiple Range Test (DMRT) using least significant difference (LSD) tests at 0.05 probability level. Pearson correlation was applied to determine the degree of relationship among the parameters of *Eichhornia crasaipes* briquettes and *Nypa fruitican* briquettes. All analysis was done using the SPSS software Version 20.0, 2020 (IBM, Chicago)

Results

Proximate Analysis

This result as summarized in Table 2, showed that *Echhornia crassipes* had a significantly (*P<0.05*) higher Moisture content with mean value 28.20 ± 1.51 than *Nypa fruticans* with mean values 20.99 ± 1.36 as represented in Figure 11. The volatile matter content in *E. crassipes* as shown in Figure 12 was significantly (*P<0.05*) higher with mean value 8.30 ± 1.34, than *N. fruticans* with mean value 4.84 ± 2.68; which also recorded a significantly (*P<0.05*) lower Ash content (19.86 ± 2.25) than *E. crassipes* with a higher Ash content (54.55 ± 3.48) (Figure 13). However, the fixed Carbon content exemplified in Figure 14, showed that *N. fructicans* recorded a significantly (*P<0.05*) higher mean value (54.39 ± 5.76) than *E. crassipes* with mean value (8.94 ± 1.71).

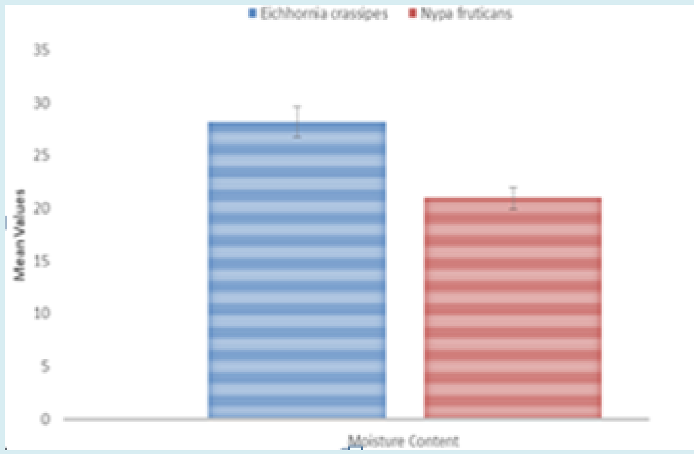

Figure 11: Moisture Content of *N. Fruticans* and *E. Crassipes* Briquettes.

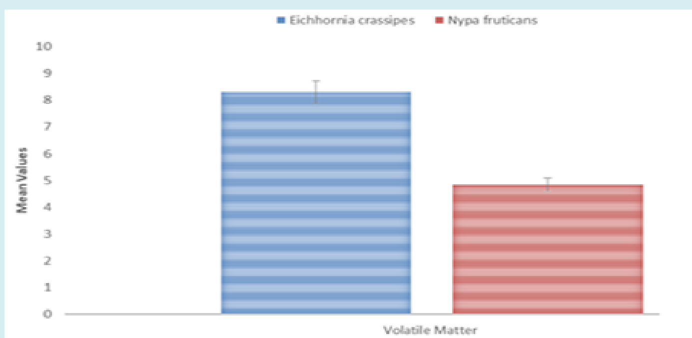

Figure 12: Volatile Content of *N. fruticans* and *E. crassipes* briquettes.

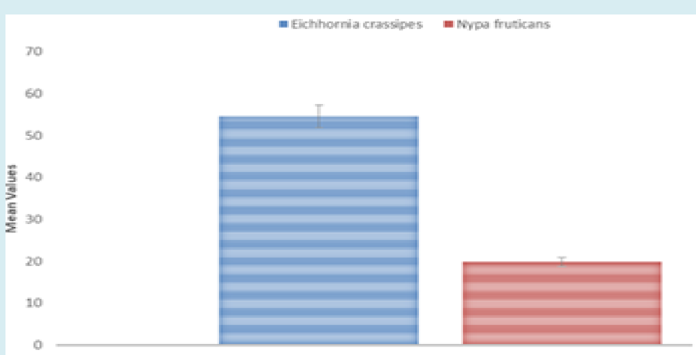

Figure 13: Ash Content of *N. Fruticans* and *E. Crassipes* Briquettes.

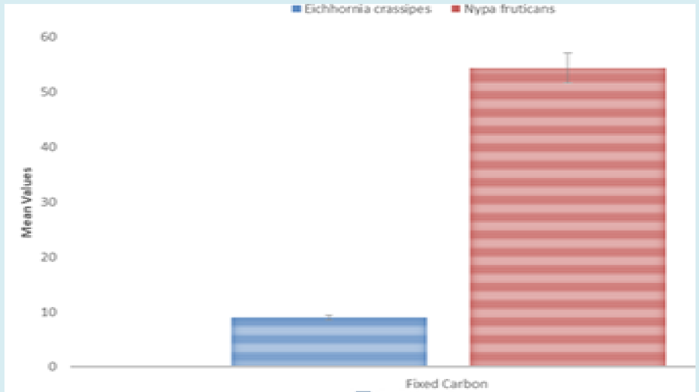

Figure 14: Fixed Carbon Content of *N. fruticans* and *E. crassipes* briquettes.

Parameters	*Eichhornia crassipes*	*Nypa fruticans*	(P<0.05)
Moisture Content	28.20 ± 1.51[a]	20.99 ±1.36[b]	0.952
Volatile Matter	8.30 ± 1.34[a]	4.84 ± 2.68[b]	0.977
Ash Content	54.55 ± 3.48[a]	19.86 ± 2.25[b]	0.771
Fixed Carbon	8.94 ± 1.71[b]	54.39 ± 5.76[a]	0.703
Bulk Density	0.001±0.00003[a]	0.002 ± 0.003[a]	1
Shatter Resistance	92.72 ± 4.65[b]	94.83 ± 2.63[a]	0.986
Ignition Time	12.67 ± 0.58[b]	19.00 ± 2.65[a]	0.958
Burning Time	8100 ± 216.33[b]	13480 ± 570.26[a]	0
Burning Rate	0.00 ± 0.00[a]	0.00002 ± 0.00003[a]	1
Water Boiling Test	730.33 ±103.76[b]	740.00 ± 69.74[a]	0.935
Specific Heat of Combustion	909.37 ± 143.04[b]	3196.55 ± 230.55[a]	0

Values are expressed as Mean ± SD

Table 2: Briquetting Characteristics of *E.crassipes* and *N.fruticans*.

Bulk Density

The result as represented in Figure 15 showed that *N. fruticans* had a higher BD with mean value 0.002 ± 0.003 than *E. crassipes* with mean value 0.001 ±0.00003. However, there was no significant difference (*P<0.05*) in the BD of both biomass briquettes.

Shattering Resistance

The result as represented in Figure 16, recorded *N.fruticans* with a significantly (*P<0.05*) higher Shattering Resistance of 94.83 ± 2.63 than *E. crassipes* with mean value (92.72 ± 4.65).

Thermal Analysis

The result as represented in Figure 17, showed *N. fruticans* with a quicker Ignition Time (IT) with mean value (13480 ± 570.26) significantly higher (*P<0.05*) than *E. crassipes* with mean value of 8100 ± 216.33. Similarly the burning time (BT) in Figure 18, showed that *N. fruticans* had a Burning Time with mean value (13480 ± 570.26) significantly higher (*P<0.05*) than *E. crassipes* with mean value of 8100 ± 216.33.

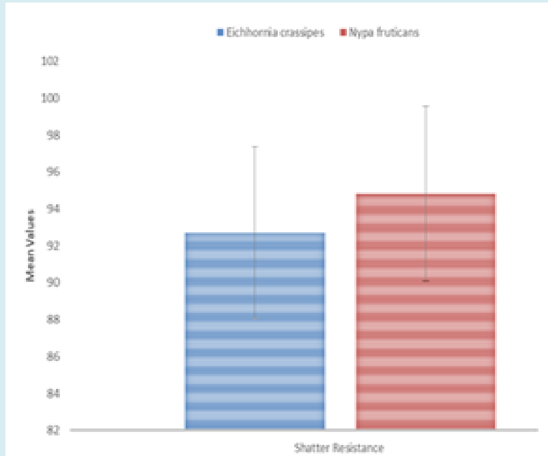

Figure 15: Bulk Density of *N. fruticans* and *E. crassipes* briquettes.

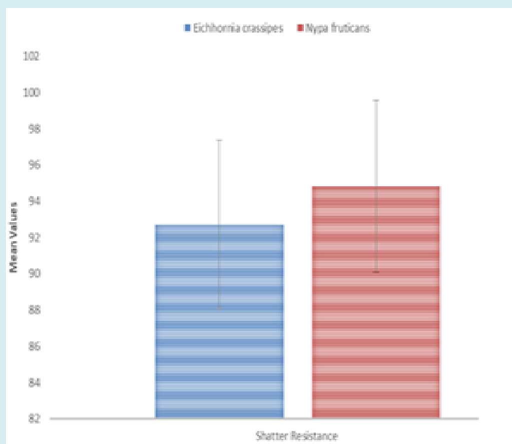

Figure 16: Shatter Resistance of *N. fruticans* and *E. crassipes* briquettes.

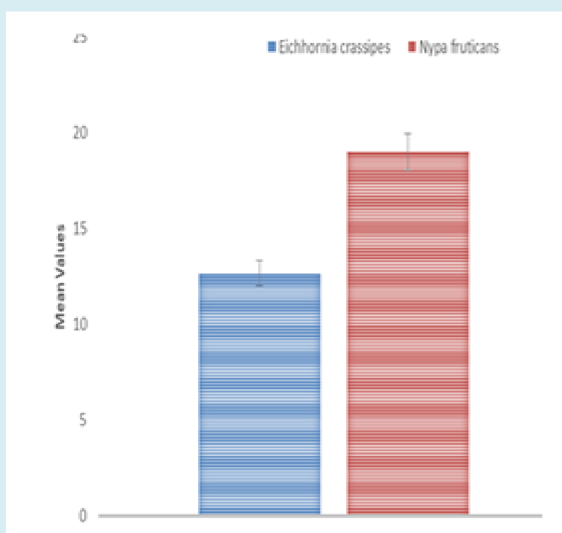

Figure 17: Ignition Time of *N. fruticans* and *E. crassipes* briquettes.

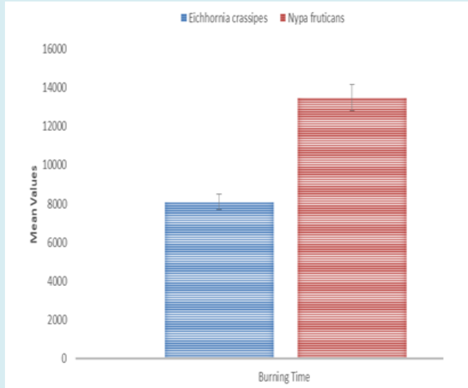

Figure 18: Burning Time of *N. fruticans* and *E. crassipes* briquettes.

The Burning rate (BR) as represented in Figure 19, showed that *N. fruticans* had a higher Burning rate with mean values 0.00002 ± 0.00003than *E. crassipes* with mean values 0.00 ± 0.00 (Table 3). However, there was no significance difference (*P<0.05*) between the two species briquettes. But the Water boiling test represented in Figure 20, showed that *N. fruticans* had a higher water boiling test with mean value 740 ± 69.74 significantly (*P<0.05*) higher than *E. crassipes* with mean value of 730.33 ±103.76.

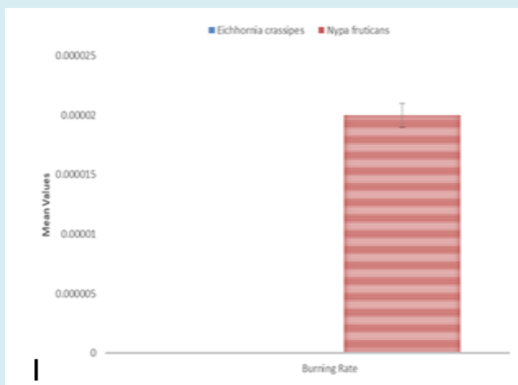

Figure 19: Burning Rate *N. fruticans* and *E. crassipes* briquettes.

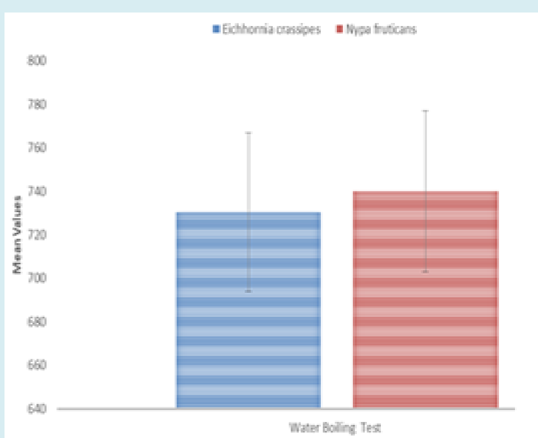

Figure 20: Water Boiling Test of *N. fruticans* and *E. crassipes* briquettes.

	MC	AC	VM	FC	IT	BT	BR	WBT	BD	SR	SHC
MC	1										
AC	.934**	1									
VM	.858*	0.691	1								
FC	-.979**	-.985**	-0.794	1							
IT	-0.772	-.895*	-0.37	.845*	1						
BT	-.922**	-.990**	-0.638	.973**	.942**	1					
BR	-0.665	-0.61	0.79	0.662	0.376	0.553	1				
WBT	-0.085	-0.115	0.024	0.065	-0.041	0.037	-0.141	1			
BD	-0.235	-0.407	0.236	0.323	0.768	0.519	-0.145	-0.278	1		
SR	-0.328	-0.319	0.037	0.279	0.403	0.336	-0.206	0.72	0.323	1	
SHC	-.977**	-.978**	-0.773	.992**	.839*	.968**	0.576	0.132	0.326	0.354	1

Table 3: Pearson Correlations of the Briquette Characteristics.
Note: MC= Moisture Content; AC= Ash Content; VM=Volatile Matter; FC= Fixed Carbon; IT = Ignition Time; BT = Burning Time; BR = Burning Rate; WBT = Water Boiling Test; BD = Bulk Density; SR = Shatter Resistance; SHC = Specific Heat of Combustion.
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Specific Heat of Combustion

The result of SHC has shown that *N. fruticans* had a significantly (*P<0.05*) higher SHC with mean value of 3196.55 ± 230.55 than *E. crassipes* with mean value of 909.37 ± 143.04 (Figure 11).

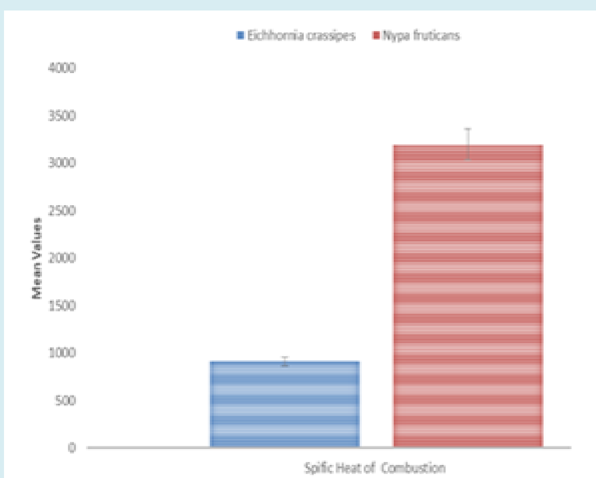

Figure 21: Specific Heat of Combustion *N. fruticans* and *E. crassipes* briquettes.

Discussion

Briquetting offers the opportunity of making flora biomass to have good biofuel characteristics and properties, thereby making biomass a good source of energy for the society with less emission when compared with fossil fuel. As presented in summary Tables 2 & 3 of briquettes indices and correlation between and among the indices respectively, this investigation focused on exploring the potentials of *N. fruticans* and *E. crassipes* in briquettes production as well as their combustion characteristics in light of their physical properties.

Based on the report the moisture content was significantly higher in *E. crassipes* briquette than in the *N. fruticans* briquette. Study shows that the tolerance level of moisture content for briquette is between 8% and 12%, which may depend on the nature of the biomass feedstock [48]. Similarly, further study has shown that a moisture content that is less than 4% or 5% will reduce the stability of briquettes [49] and make the briquette too dry, hence making it burn out quickly. This was observed as exemplified in a significantly negative correlation between the MC and BT (r = 0.922, $P< 0.05$) in the present study (Table 3). Moisture content in briquette is considered as an impurity and could lower the heating value [50].

The liquids present in the charcoal other than water which are easy to vaporize are called volatile matters (VM). The briquetting characteristics have recorded significantly higher volatile matter content in *E. crassipes* than in *Nipa* briquettes. Large moisture content results in the formation of fumes It was observed that the moisture content of these briquettes weren't less than 5% which made the briquette stable, and also were not very high preventing the formation of fumes as it is seen in a strong positive correlation with volatile matter (r = 0.858; $P< 0.05$). This corroborates the findings of Rezania, et al. [51] in their production of briquettes using *E. crassipes*, empty fruit bunches of oil palm (palm oil mill residue) and cassava starch.

High fixed carbon content of a briquette means it is mostly made up of carbon. In this present study, it was observed that as the moisture content decreased, the fixed carbon content of the briquette also increased. This possibly could have contributed to more carbon atoms in *Nipa* briquette. Compared with the *E. crassipes* briquette produced, it had a significantly higher fixed carbon with a strong negatively significant correlation (r = - 0.979; $P<0.05$). The Briquette characteristics showed that the briquettes having higher fixed carbon have lower ash content. This corroborates a strongly negative correlation (r = - 0.985; $P<0.05$) between the fixed carbon and Ash content. The fewer the residues left after combustion, the greater amount of fixed carbon and combustible substance such as the volatile matter content present. Also, the ash content was found to decrease as moisture content decreased, which also corroborates a strong positive correlation (r = 0.934; $P<0.05$) between the Ash and moisture properties.

Density is an important parameter for the briquetting process. The density of the feedstock, binder, briquetting pressure, temperature and time, to a large extent, determines the eventual density of the briquette [52]. The higher the density in briquettes, the higher the energy/volume ratio as well as the longer the burning time [53], however, other combustion properties of such briquettes may be negatively affected [54]. Report from the study has shown that *E. crassipes* briquette displayed a lower bulk density mean value than the *Nipa* briquette with higher BD and BT. This can be exemplified in highly positive significant correlation (r = 0.519 $P<0.05$) between BD and BT, which implies that a higher BD will result to a longer BT. It has been opined that briquette density is affected significantly by the raw material particle size, wherein finely ground materials make very dense briquettes [55]. This corroborates the assertion by Mitchual et al. [56] who posited that raw material with finer particles size provides a larger surface area for bonding, which results in the production of briquette with a higher density. Owing to the inclination to absorb water, the lower values of *E. crassipes* briquette could be due to a decrease in the briquette weight or a rise in the briquette volume after drying and stabilizing, as observed by Okot, et al. [57]. Studies have also noted that briquettes produced from hydraulic piston presses have unit densities lower than 1.00 g/cm3 because of limited pressure [49] which was the method with which this briquette was produced. For economic purposes, low density raises the costs of briquette transportation and decreases the energy density.

Shatter resistance is a direct means of gauging the strength of briquettes for the purposes of handling, transportation and storage. In recent study it has been recorded that *Nypa* has a significantly higher shatter resistance than *E. crassipes* making them very good for transportation and storage as they won't easily break off. The present study has recorded a corresponding synergy in the increased shatter resistance of *Nypa* briquette with a decrease AC and VM as well as increased FC, BD, IT, BT and SHC. This corroborates a negative correlation (r = -0.319; $P<0.05$) between SR and AC; positive correlations (r = 0.037; $P<0.05$) between SR and VM; (r = 0.279; $P<0.05$) between SR and FC; (r = 0.323; $P<0.05$) between SR and BD; (r = 0.403; $P<0.05$) between SR and IT; (r = 0.336; $P<0.05$) between SR and BT and (r = 0.034; $P<0.05$) between SR and SHC. It has been asserted that the shatter index of briquettes should be at least 90% [58]. However, a minimum value of 50% can also be considered an acceptable shatter index for fuel briquettes developed for industrial and domestic applications [59].

It is has been shown that Burning rate of the *E. crassipes* briquettes increased with increased volatile matter as it burns faster than *Nypa* briquette which correlates positively (r = 790; $P< 0.05$). Density has been reported as a parameter that can influence the combustion rate and is characterized by low porosity and reduce the infiltration of oxidant and outflow of the combustion products during combustion .This can be exemplified in a negative correlation (r = -0.145; $P<0.05$) between BD and VM. The density influences the flame propagation in briquettes; fewer free spaces for mass diffusion (low porosity), hinders drying, depolarization and burning. Reduction in porosity and consequently increasing density can influence the combustion rate of briquettes by hampering the outflow and infiltration rate of oxidant during combustion.

A higher quantity of specific heat value was produced by the *Nypa* briquette compared to *E. crassipes*. The high quantity of heat energy produced is a result of the high content of carbon it has and the less amount of moisture in it hence it can improve heat release. This can be exemplified in a significantly positive correlation (r = 0.992; $P<0.05$) between SHC and FC and significantly negative correlation (r = -0.977; $P<0.05$) between SHC and MC. The quantity of heat released was seen in action on the water boiling test as the briquette boiled 100ml of water with the respective mean value for the two species biomass proving *Nypa* briquette to give out more heat quantity. This corroborates the positive correlation (r = 0.132; $P<0.05$) between SHC and WBT. The results of the proximate, mechanical and thermal analysis show that the *Nypa* biomass had a better potential in biochar energy than *E. crassipes* which indicate *Nypa* as a good briquette.

Conclusion

From the findings of this project it is quite evident that briquetting for energy production from *N. fruticans* and *E. crassipes* is an appropriate means of regulating invasion of these species on water ways. It was observed that the Volatile matter content of these species briquettes was extremely low and these volatiles are water vapour leaving the briquettes. The Ecosystem can duly be restored by the replacement of some harmful sources of energy by this briquette specifically as the supposed harmful substances (carbon mono-oxide, carbondioxide and sulphur) are not released into the atmosphere on its use. These substances were trapped and taken out from the briquette during the process of carbonization making the briquette ecosystem friendly and a good source of energy. Energy production is evolving and the need to produce a good and profitable energy is necessary. Renewable energy from biomass materials offers this opportunity as it serves a neutral carbon source. It can therefore be strongly recommend there should be a total deviation from deforestation for energy production to an exploitation of biomass materials in Briquetting. Importantly, the process of carbonization should be practiced as this would not degrade the ecosystem.

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