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Briquetting of Aquatic Biomass Feedstock: An Untapped Ecological Potential as Alternative Source of Biofuel Energy for Sustainable Ecosystem Restoration

Nsirim Lucky Edwin-Wosu*, Zinabari Confidence Dee-Ue

Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Port Harcourt, Nigeria

Email address:

nsirim.edwin-wosu@uniport.edu.ng (Nsirim Lucky Edwin-Wosu)

*Corresponding author

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Abstract: *Background: Eichhornia crassipes* (Mart) Solms and *Nypa fruticans* Wurmb (invasive halophyte) are alien aquatic flora highly troublesome with a consequence of altering sea route navigation, displacing traditional indigenous mangal species and general loss of mangrove biodiversity and aquatic lives. Both species are highly prolific with endowed untapped renewable biomass resources. *Aim*: This study was aimed at biotransforming *Eichhornia crassipes* and *Nypa fruticans* biomass for briquette production, with the objectives of converting them to biochar as an approach to sustainable aquatic weed management. *Method*: Standard procedures of sample collection, processing by sun drying / oven drying, carbonization, and densification methods and data analyses by ANOVA were adopted. *Result*: Result has recorded a significant difference ($P < 0.05$) between species, with *Nypa fruticans* higher in Ignition time (Kg/s) (50.67 ± 3.06); fixed carbon (%) (47.20 ± 2.38); burning time (Kg/s) (7368 ± 2049.26); bulk density (g) $3.54 \times 10^{-4} \pm 6.6 \times 10^{-6}$, specific heat of combustion (Kcal/kg) (3620.86 ± 113.71) and a non-significant shattering resistance (%) (91.63 ± 9.48). *Eichhornia crassipes* had a significant water boiling test (Cm^2/s) of 2080±150.99; moisture content (%) (34.38 ± 2.21); burning rate (Kg/s) $4.00 \times 10^{-6} \pm 17.0 \times 10^{-6}$, volatile matter (%) (32.75 ± 1.00) and ash content (%) (38.66 ± 1.86). *Conclusion*: Therefore, based on the result *Nypa* palm biomass can be a better energy source of briquette and with the use of aquatic plants as alternative option for renewable energy source of briquette, both species may not only serve as medium of conserving our forest but also help in clearing the water ways and control pollution.

Keywords: *Eichhornia crassipes*, *Nypa fruticans*, Starch, Biochar, Biomass

1. Introduction

Environmental pollution is one of the most serious global challenges and problems facing humanity and other life forms on earth today. It can be described as any unfavorable alteration of our surroundings, wholly or largely as a byproduct of anthropogenic and natural intrusions to such an extent that normal environmental (physical and biological components) processes are adversely affected [1, 2]. Over the past couple of decades, various sources of pollution that altered the composition of water, air and soil system of the environment were identified [3]. Depending on the nature of pollutants and subsequent pollution of environmental components, pollution may be air, water, and soil / land pollution. Amongst these types of pollution, water pollution is one of the most common types threatening the environment and living organisms [4].

Water pollution can be viewed as the release of substances of liquid, gaseous and solid materials and / or their byproducts into surface water (lakes, streams, rivers, estuarine and oceans) and ground water to the point where the substance interfere with beneficial use of the water or with the natural functioning of ecosystem [3]. Beside other sources of aquatic pollution it can also be biological in nature [5], as exemplified with alien species among the aquatic ecosystem in parts of Nigeria [6]. Alien species (sometimes known as invasive species) are plants from one region been introduced into a different ecosystem outside their normal environment where they do not belong, they have no actual predators so they rapidly run wild, crowding out the usual natural traditional plants that thrives in such environment. Common examples of alien Species include *Caulepra taxifilia*, *Potamocarbula amurensis*, *Eichhornia crassipes* and *Nypa fruticans* [5].

Eichhornia crassipes (Mart.) Solms, is a free floating aquatic weed and the world's most difficult waterweed to control [7]. It is considered a highly invasive weed, infecting dams, lakes and irrigation channels in most tropical and subtropical region. One major problem associated with *Eichhornia crassipes* is its rapid growth rate. It can easily compete and adapt with other aquatic plant causing a major threat to the aquatic environment [8]. Excessive amount of *Eichhornia crassipes* in the aquatic system can reduce biodiversity, displace native species, damage hydroelectric system and affect water quality and flow as well as navigation route. When not managed and controlled, the plant causes blockage of water bodies resulting to floods, during heavy rainfall and typhoons [7].

Nypa fruticans Wurmb known as the tap palm (Singapore), Nipa palm (Philippines) and mangrove palm is the only palm considered a mangrove. This species, is the only one in the genus Nypa, grows in Southern Asia, Northern Australia as well as Niger Delta region of Nigeria [9]. *Nypa fruticans* (Nypa palm) usually inhibits estuarine habitats across the areas of colonization and invasion. *Eichhornia crassipes* and *Nypa fruticans* have infested Rivers, Lakes and creeks in Rivers State affecting the livelihood of millions of its inhabitants [6]. As a result of their rapid and incensed growth they have become limitation to water transportation activities [10], pose threats to other aquatic activities like swimming, fishing and prevent sunlight from reaching the water columns, thus disrupting photosynthetic processes [11]. In habitat where *Nypa fruticans* is dense, mangrove vegetation habitat for breeding of fish is been chocked thus contributing to the decline in fish population of that area [12]. People living in areas where there is an intense growth of these plants species have limited knowledge of the different ways of utilizing them. Those who utilize the raw *Nypa fruticans* as fuel ends up inhaling smoke which emanates from burning of the fronds and nuts which when inhaled continuously results to eye and respiratory diseases.

Though *Eichhornia crassipes* and *Nypa fruticans* are considered by many countries as weed associated with many environmental and health problems, these plants infestation is never eradicated instead it is a situation that must be continually managed, [13]. Therefore, control by utilization remains the only sustainable option of dealing with the weed as this takes up great quantity of the weed at a time [8]. Research has documented their value chain among which include: heavy metals removal from aquatic system [14], pretreatment of polluted water [15], Biogas production [16], Basket making as well as biocharcoal production and energy briquetting [17]. However, this research work seeks to utilize the ecological potential of *Nypa fruticans* and *Eichhornia crassipes* as a plant based biocharcoal briquettes for a sustainable environmental pollution control measure for aquatic ecosystem in River State.

This study will be of high significant value in light of its financial and economic value chain hence the biocharcoal briquette end product of *Nypa fruticans* and *Eichhornia crassipes* would have the potential of: meeting the additional energy demands of rural, urban and industrial sectors, contribute to significant economic advancement as alternate energy source for human consumption, create employment opportunities, making the raw materials for briquetting affordable and abundant in our immediate environment, saves cost of waste disposal thereby sustaining a healthy environment. This study will help provide technology protocol for producing briquettes in rural areas where there is lack of electricity. It will aid reduction in deforestation, and a tremendous shift from the use of petroleum products (kerosene, coal and liquefied petroleum products) to the use of biomass briquettes as industrial and domestic fuel; thus would help reduce the greenhouse effect since biomass is carbon neutral. The results of this study would extend the knowledge in producing briquettes from aquatic plants. It would help to diversify the sources of energy in Nigeria, and therefore help to improve the energy security in Nigeria.

2. Materials and Methods

2.1. Description of Study Area, Location and Site

The study areas are Obio/Akpor and Ahoada-East local government councils in Rivers State (Figure 1) Nigeria.

The Obio/Akpor study area (Figure 1) is located at latitude 4°52'34.112"N and longitude 6°59'58.497"E and with a coverage of about 260km^2, a tropical mansoon climate characterized annually by maximum rainfall, sandy silt or sandy loam soil and clayey underlain by a section of impervious pan often leached alkaline or salty and sometimes acidic in nature as a result of heavy rainfall [18]. It houses about 46 habitations consisting of localities, towns and suburbans including Rumuokparali study location (Figure 2) [19]. The Rumuokparali study location (Figure 2) with its situate at latitude 4°51'44.262"N and longitude 6°54'24.58"E is an agrarian community but with fishing and trading as alternative source of livelihood. The location is known for its popular River: the Rumuokparali River (study sampled site Figure 3), a fresh water ecosystem but brackish and tidal at the upstream; with it situate between longitude of 6°54.17E and latitude 04°52.37N, and distance coverage of 551.09 meters to Choba bridge. The River is a hub of Industrial and domestic trading activities of the local inhabitants of the area. It is a point of effluent discharge from Industrial and Domestic operations, as well as waste emptied into it from the surrounding local market and Abattoir located close to the River [20]. The site is characterized by both fresh and brackish water flora species including: *Nypa fruticans, Rhizophora recemosa, Avicennia germinans, Pandanus leram, Rhizophora mangle, Raffia hookeri* etc.

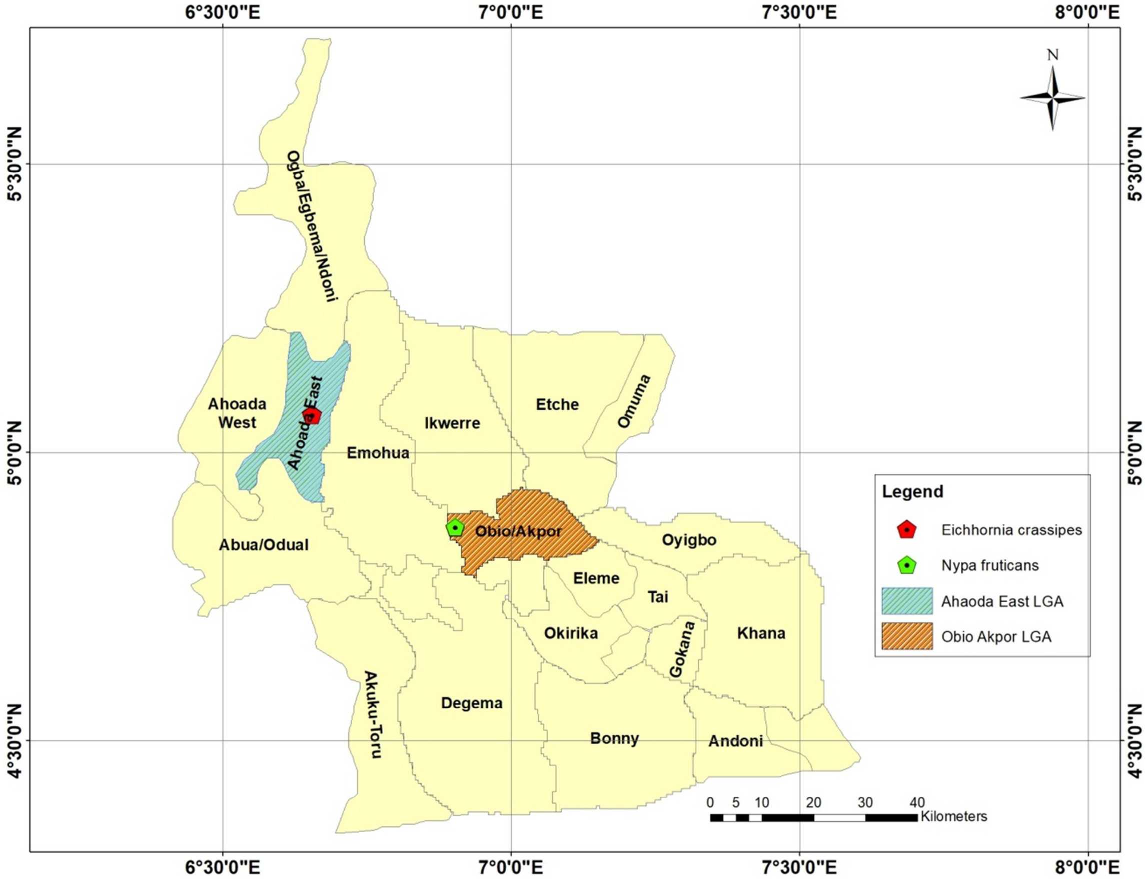

Figure 1. *Rivers State Indicating Ahoada-East and Obio/Akpor Study Areas.*

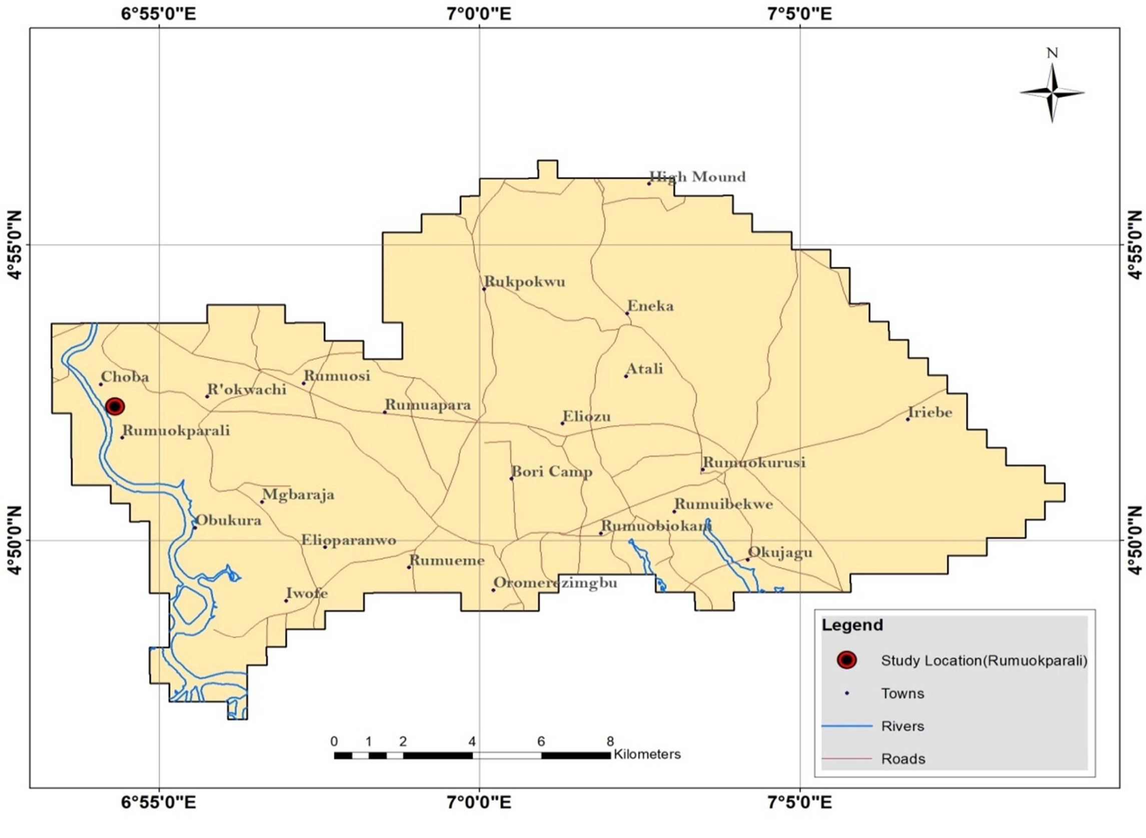

Figure 2. *Obio/Akpor study Area indicating Rumuokparali study location.*

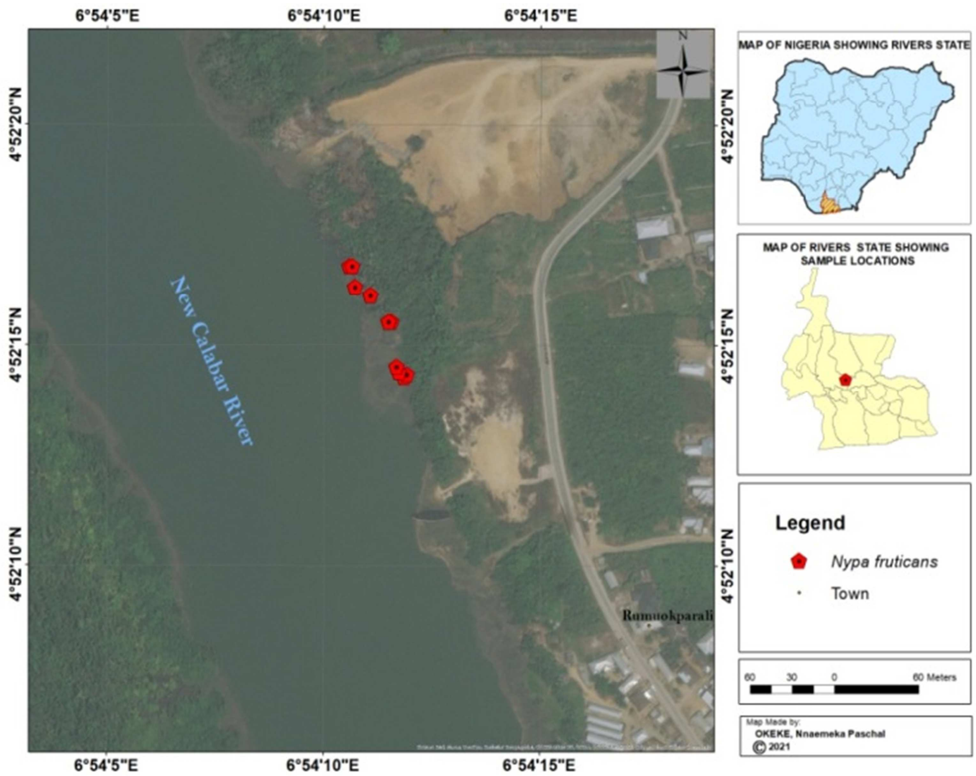

Figure 3. *Satellite imagery of the Rumuokparali River study sampled site indicating the sampled point coordinates.*

The Ahoada East study area (Figure 1) is situated at latitude 5°3'40.509"N and longitude 6°38'30.714"E with its headquarters as Ahoada town in Rivers state, South-South geopolitical enclave of Nigeria. The area houses about 86 habitations of towns and villages [19] including Ahoada study location (Figure 4). The study location is known for their agrarian prowess, and also fishing and hunting as alternative source of livelihood. It is majorly characterized by the Sombrerio River (study sampled site Figure 5) with its situate at latitude 5°4'2.044"N and longitude 6°39'26.14"E [21]. The River with possible fresh water input is dominated with fresh water species including; *Bambusa vulgaris, Raphia hookeri, Nymphaea lotus, Nymphaea maculata, Pennisetum purpureum. Crinum natans,* and *Azolla pinnata.*

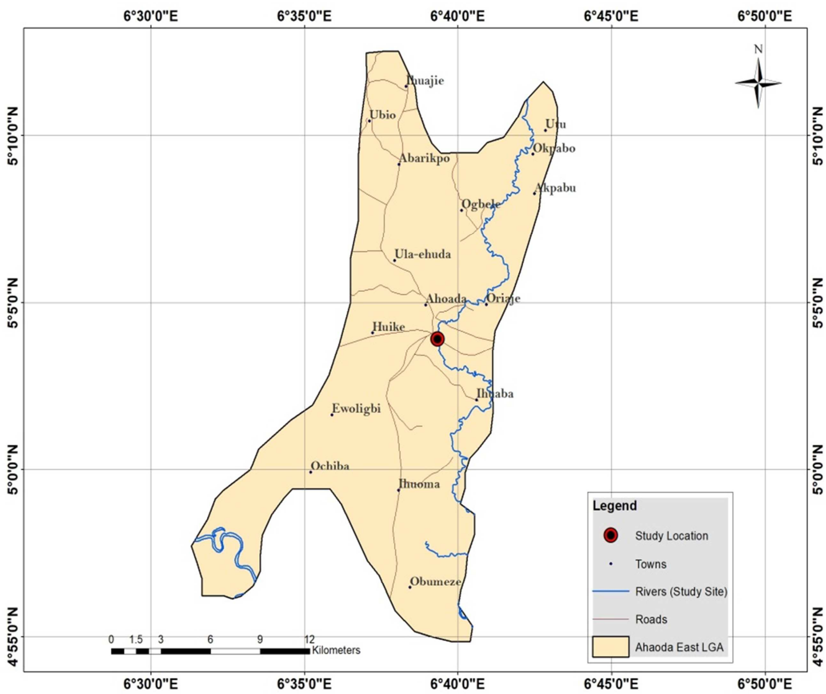

Figure 4. *Ahoada-East study location indicating Sombreiro River study site.*

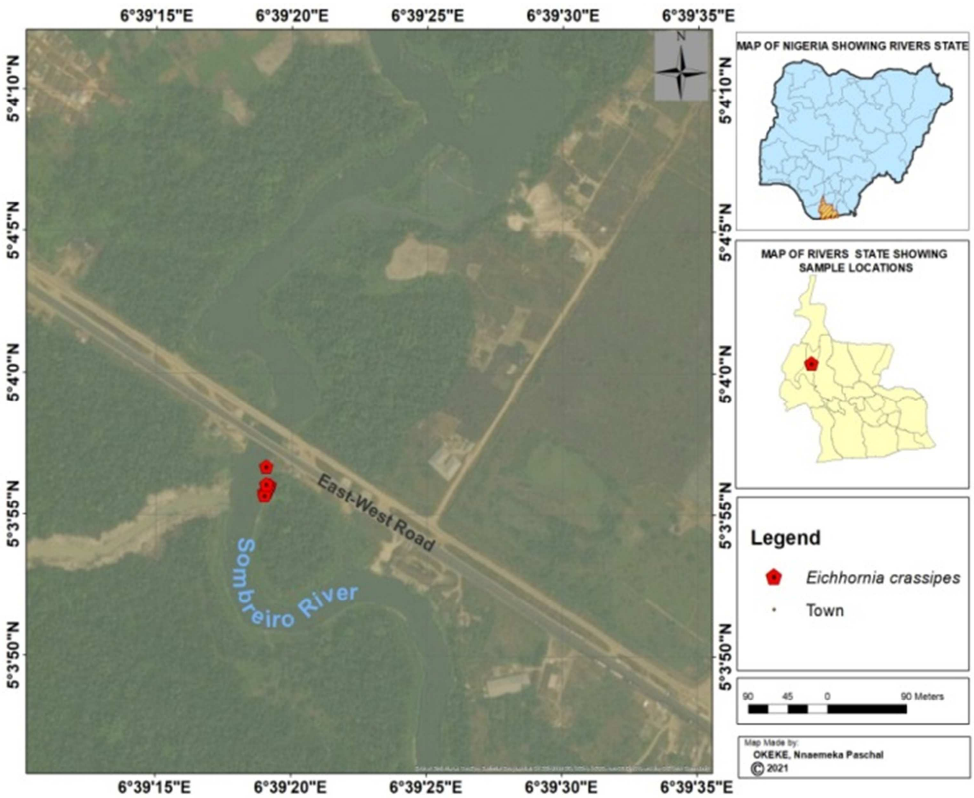

Figure 5. *Satellite imagery of Sombreiro River study site indicating the sampled point coordinates.*

2.2. Sampling of Biomass Feedstock

A random system of sampling as stated by Lawal *et al*. [22] was adopted. The *Eichhornia crassipes* (Figure 6(a)) was randomly picked from the Sombreiro River by uprooting the entire plant to ensure the whole biomass was intact. This was carefully done to ensure the entire biomass of the sample on fresh weight bases was maintained. *Nypa fruticans* (Figure 6(b)) was collected randomly from the Rumuokparali River by cutting the mature fronds with a machete. 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.

(a)

(b)

Figure 6. *Fresh biomass feedstock (a) E. crassipes & (b) N. fruticans.*

Table 1. *GPS Coordinates of Sampling Points for Biomass.*

Eichhornia crassipes (Mart) Solms			
Sampled Points	**Lat. (North)**	**Long. (East)**	**Alt. F**
1	05°, 03.934'	006°, 39.324'	9
2	05°, 03.934'	006°, 39.324'	6
3	05°, 03.934'	006°, 39.323'	0
4	05°, 52.242’	006°, 39.323'	0
5	05°, 52.259’	006°, 39.323'	-1
6	05°, 52.259’	006°, 39.323'	2
7	05°, 52.259’	006°, 39.323'	3
8	05°, 03.930'	006°, 39.321'	4
9	05°, 03.930'	006°, 39.322'	5
10	05°, 03.928'	006°, 39.321'	6
11	05°, 03.945'	006°, 39.322'	7
12	05°, 03.945'	006°, 39.322'	9

Eichhornia crassipes (Mart) Solms			
Sampled Points	**Lat. (North)**	**Long. (East)**	**Alt. F**
Nypa fruticans Wurmb			
1	04°, 52.238’	006°, 54.201'	16
2	04°, 52.239’	006°, 54.202'	13
3	04°, 52.240’	006°, 54.199'	9
4	04°, 52.242’	006°, 54.198'	9
5	04°, 52.259’	006°, 54.196'	14
6	04°, 52.259’	006°, 54.195'	10
7	04°, 52.259’	006°, 54.195'	9
8	04°, 52.269’	006°, 54.188'	8
9	04°, 52.269’	006°, 54.188'	14
10	04°, 52.272’	006°, 54.182'	9
11	04°, 52.280’	006°, 54.180'	10
12	04°, 52.280’	006°, 54.181'	9

2.3. Processing of Sampled Biomass

2.3.1. Drying

After collection, samples were carefully sorted out to remove unwanted twigs and washed to get rid of impurities. The initial moisture content was determined as described by Tembe *et al.* [23] by measurement on fresh weight basis. Both materials as described by Aboagye [24] were then sun dried gradually for a period of 96 hours at 30-35°C to get rid of the moisture content in the plant and subsequently oven dried at temperature of 105°C for 24 hours to reduce the moisture content (Figure 7). The entire processing and analyses were carried out in Chemical Engineering Laboratory, University of Port Harcourt.

(a)

(b)

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

2.3.2. Carbonization of Biomass to Biochar

Carbonization of biomass adopted Tembe *et al.* [23] method using a murfle furnace (Carbolite Sheffield England LMF 4) under controlled oxygen. 1000g of the *Nypa* biomass was weighed into the murfle furnace and carbonized at a temperature of 450°C for a period of 20-25mins, while same grams of *Eichhornia* biomass was carbonized at temperature of 450°C for about 55-65mins. Both biochar were allowed to cool at room temperature for three hours prior to briquette production. Upon removal of samples from the furnace, clean water was sprinkled over the sample to facilitate the cooling process and prevents ashing.

2.3.3. Particle Size Reduction

Particle size reduction based on Aboagye [24] method was adopted with the aid of a local crusher (motar and pistol) to reduce the size of the biomass to about 1mm diameter and screened through 1mm diameter mesch seive to enable a good binding surface area. The larger particles were further subjected to size reduction until an even particle size was achieved.

2.3.4. Application of Binder

The binding process was based on Emerchi [25] method in which a natural polymer (Starch material from cassava) was gelatinized with boiled water at 100°C to make a gelatinous mass. The binder versus biomass ratio was determined by varying the grams of starch added to a fixed biomass feedstock [24], whereby 90-93grams of starch was added to about 30-32grams of *Eichhornia* biomass while 137-138grams of starch was added to 35-40grams of *Nypa* palm biomass.

2.3.5. Briquetting of Biochar and Densification Process

The briquetting and densification process was done by adopting Emerchi [25] method. After the starch binder was added in their respective quantity, the sample was mixed thoroughly then discharged into a briquetting mould, upon which a hydraulic piston press machine was screwed manually to achieve a higher pressure under constant operating conditions (temperature of 28°C) sufficient to bind the sample together inside the mould. The sample took the shape of the mould and was allowed for about 5mins then unscrewed and pulled out from the mould [24]. After densification, the resultant briquettes were placed in an oven (Figure 8) and left to dry dried at a temperature of 105°C for a period of 6-8hrs to completely dry before testing for properties. Briquettes were made from each biochar sample (Figure 9) and with their initial densities measured.

Figure 8. *Briquette in oven.*

a

b

Figure 9. *Dried briquette (a: Eichhornia briquettes & b: Nypa briquettes).*

2.4. Briquettes Characterization

2.4.1. Proximate Analysis

This involves the percentage moisture content on fresh weight basis as adapted in Tembe *et al.* [23] approach, while percentage volatile matter adapted the Emerchi, [25] method The standard test method for percentage ash content-ASTMD D2866-96 was used following Tembe *et al.* [21] method, while the percentage fixed carbon was based on Aboagye, [24] approach.

2.4.2. Thermal Analysis

This analysis involving briquette ignition time (IT), burning rate (BR) and burning time (BT) was based on Onuegbu *et al.* [26] method while the water boiling index (WBI) was also based on Onuegbu *et al.* [26].

2.4.3. Bulk Density (BD)

The bulk density measurement of the sample of briquette is done by measuring the volume of water displaced by the appropriate mass of the briquette following following Aboagye [24] method.

2.4.4. Specific Heat of Combustion (SHC) and Shattering Index Determination

The energy content of the briquette was determined based on using bomb calorimeter method of Fuizal *et al.* [27] while the percentage shatter resistance test to ascertain the durability of the briquettes was determined using the Ghorpade, [28] and Sengar *et al.* [29] methods.

2.5. Data Analysis

The data from characterization were subjected to one-way Analysis of Variance (ANOVA), descriptive statistics that includes mean and standard deviation of estimates 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 crassipes* briquettes and *Nypa fruticans* briquettes. All analysis was done using the SPSS software Version 20.0, of 2020 (IBM, Chicago).

3. Result

Result of the proximate analysis as presented in Figure 10 indicated a significant difference (*P< 0.05*) in the % moisture content of both briquette samples with *Eichhornia* briquette recording a high mean value of 34.38±2.21 than *Nypa* briquette (11.83± 0.19), which also recorded a significantly (*P<0.05*) lower % volatile matter (24.27± 0.87) than *Eichhornia* briquette with a high mean value of 32.74±1.00 as exemplified in Figure 11.

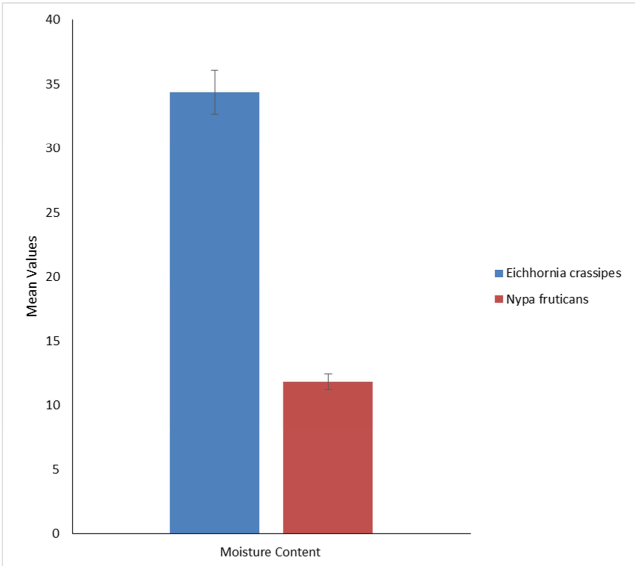

Figure 10.% *Moisture Content of Nypa and Eicchornia briquettes.*

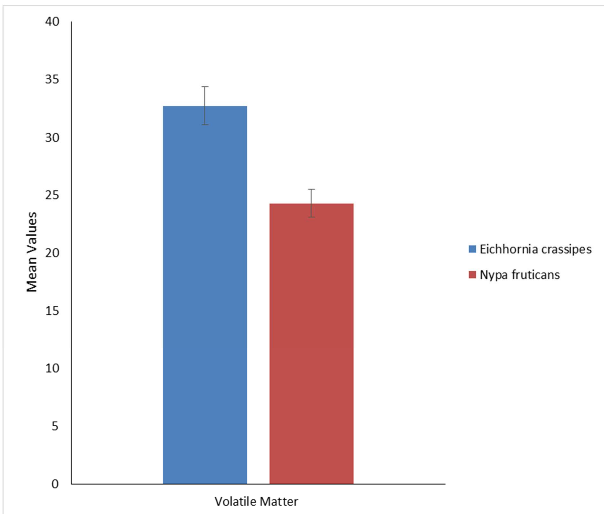

Figure 11. *Volatile Matter (%VM) of Nypa and Eicchornia briquettes.*

The percentage ash content (% AC) as exemplified in Figure 12 has recorded a lower content (28.99±2.52) in *Nypa* briquette than *Eichhornia* briquette (38.38±1.86) with significant difference *(P<0.05)*, which however recorded a significantly *(P<0.05)* lower % fixed carbon content (29.84±2.51) than *Nypa* briquette with a % value of 47.19±2.38 fixed carbon as presented in Figure 13.

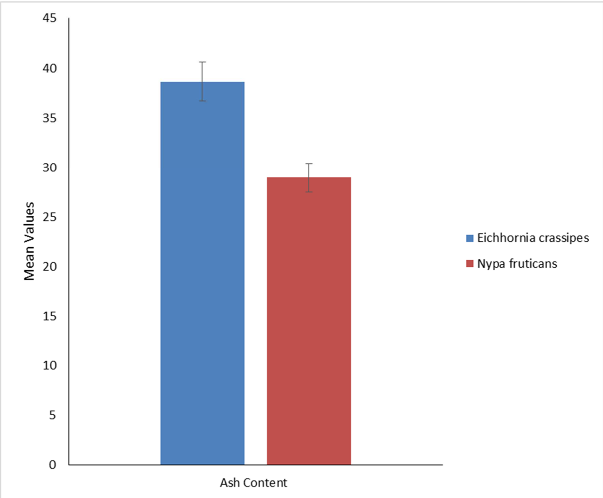

Figure 12. *Ash Content of Nypa and Eicchornia briquettes.*

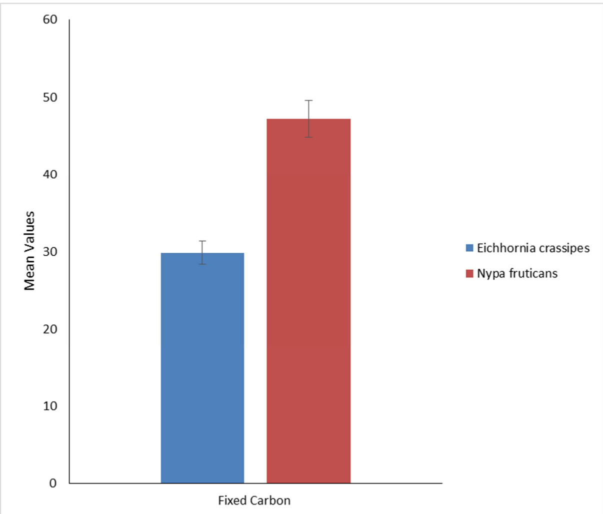

Figure 13. *% Fixed Carbon of Nypa and Eicchornia briquettes.*

The result of thermal analysis as presented in Figure 14 has indicated a significant difference *(P<0.05)* in the ignition time (Kg/s) of both briquette samples with *Nypa* briquette recording a high mean value (50.67±3.06), than *Eicchornia* briquette (30.67±3.06), which however recorded a non-significantly *(P<0.05)* higher burning rate (Kg/s) with mean value of 4.00 $x10^{-6} \pm 17.0x10^{-6}$, than *Nypa* briquette (4.00 $x10^{-6} \pm 2.00x10^{-7}$) as represented in Figure 15. The burning time (Kg/s) as presented in Figure 16 indicated a significant difference *(P<0.05)* in the briquette both samples with *Eichhornia* briquette recording a low mean value of 5952±1862.39 than *Nypa* briquette *with* mean value of 7368±2049.26 which however, recorded a significantly *(P<0.05)* lower water boiling index (Cm^2/s) value (1340±150.99) than *Eicchornia* briquette with high water boiling index value (2080±150.99) as exemplified in Figure 17.

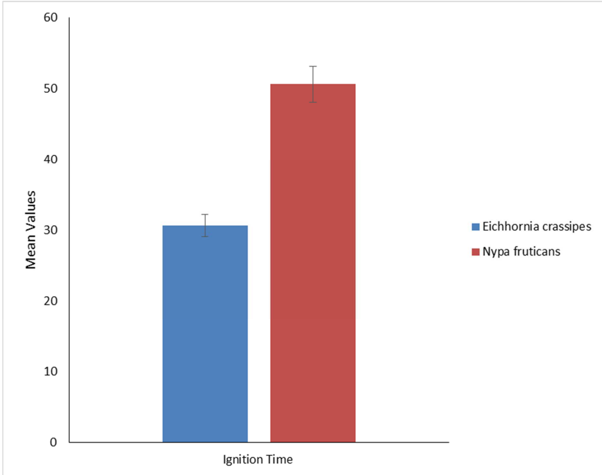

Figure 14. *Ignition Time of Nypa and Eicchornia briquettes.*

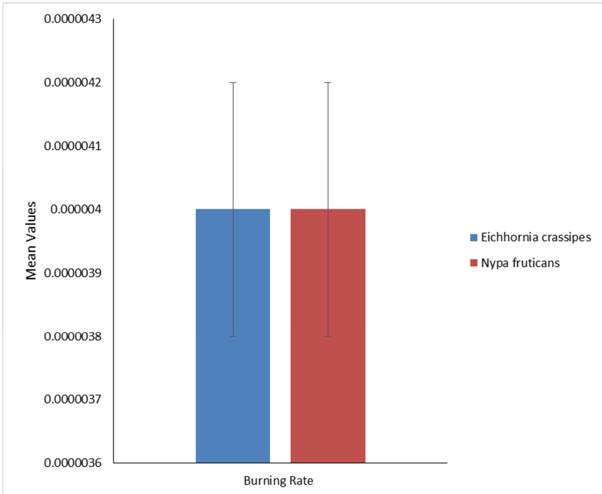

Figure 15. *Burning Rate of Nypa and Eicchornia briquettes.*

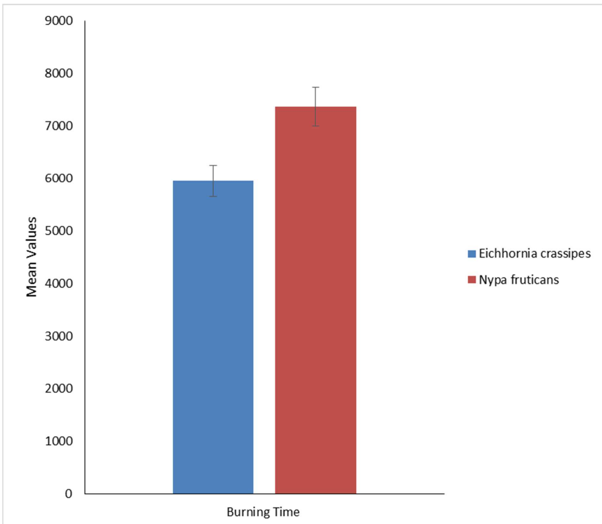

Figure 16. *Burning Time of Nypa and Eicchornia briquettes.*

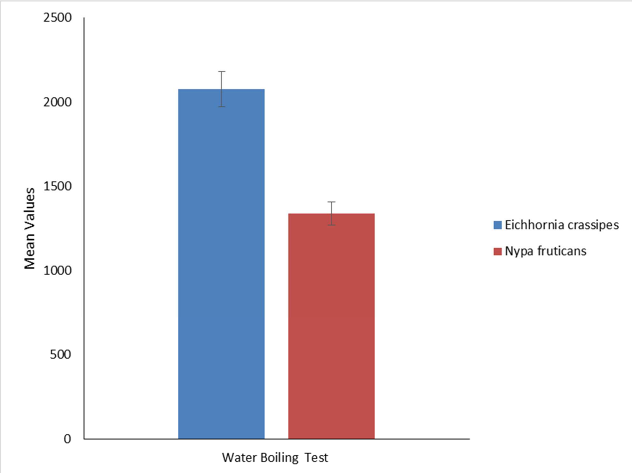

Figure 17. *Water Boiling Test of Nypa and Eicchornia briquettes.*

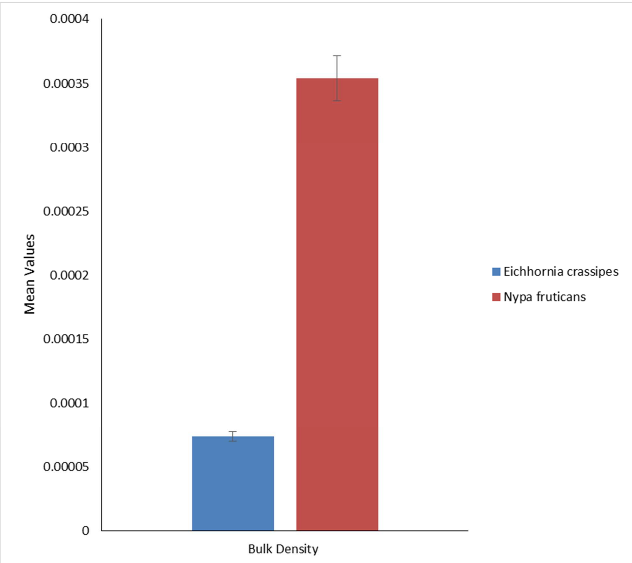

Figure 18. *Bulk Density of Nypa and Eicchornia briquettes.*

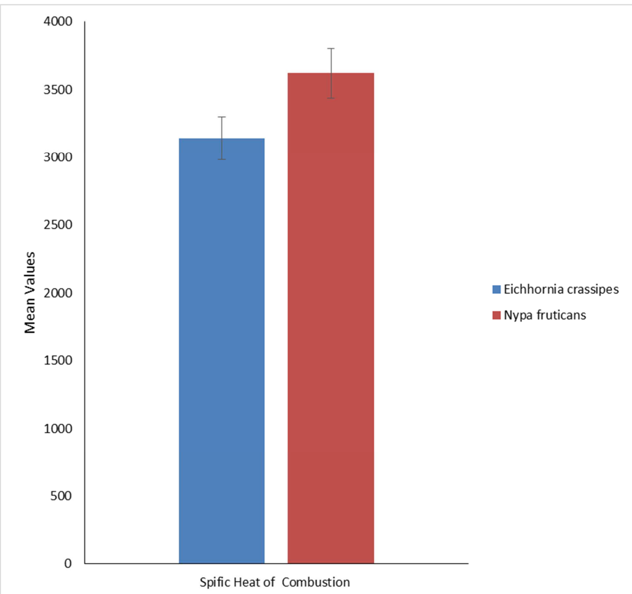

Figure 19. *Specific Heat of Combustion of Nypa and Eicchornia briquettes.*

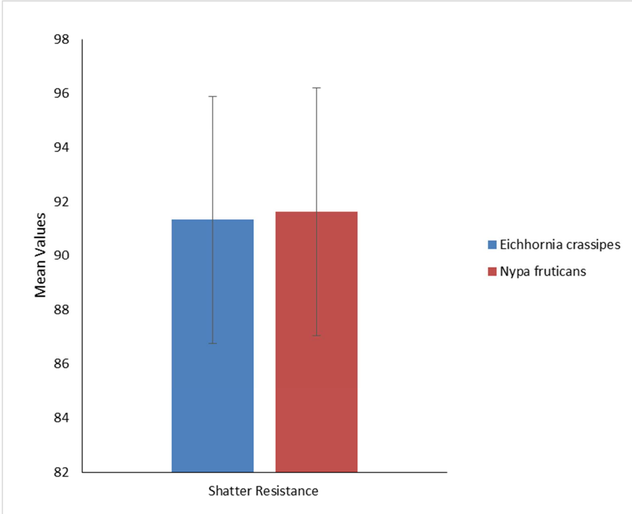

Figure 20. *Shattering Resistance of Nypa and Eicchornia briquettes.*

The result as presented in Figure 18 indicated a significant difference *(P<0.05)* in the bulk density (g) of both briquette samples with *Nypa* briquette recording a high mean value of 0.000354±0.0000066 ($3.54\times10^{-4}\pm6.6\times10^{-6}$) than *Eichhornia* briquette with low mean value (0.000074± 0.000021) ($7.40\times10^{-5}\pm2.12\times10^{-5}$) and which also recorded a lower SHC with mean value (314.81± 96.78) significantly lower than *Nypa* briquette with a high mean value of 3620.86±113.71 as represented in Figure 19. The result as presented in Figure 20 indicated a non-significant difference (*P<0.05)* in the shattering resistance of both briquette samples with *Eichhornia* briquette recording a low shattering resistance of 91.33±4.29 than *Nypa* briquette with high mean value of 91.63 ± 9.48.

4. Discussion

Based on the submission from the present research the rational and significance of exploring the potential of under utilized biomass feed stock of invasive alien species as briquettes is being revealed; thus making them good biofuel sources of alternative energy. The usefulness of the briquette characterization as summarized in Tables 2 & 3 has revealed a comparative advantage between the biomass feed stock in light of their physical properties. Based on the proximate analysis it can be observed that the moisture content for *Nypa* briquettes was less than 20% which made the briquette stable while that of *Eichhornia* briquettes was in excess, higher than 20% making it unstable. There was a significant difference between the moisture content of both briquettes. Moisture content in briquette is considered as an impurity and could lower the heating value [24]. Research has indicated that when the moisture content is lower than 10% or higher than 18%, the briquettes are not consistent and they tend to fall into pieces [30]. Similar study has recorded moisture content ranging from 15.32% to 16.82% for paper rice husk and coconut coir briquettes [31]; and these values tend to be higher than the values obtained for *Nypa* briquette in this research. High percentage of moisture in biomass materials prevents their applications for thermo-chemical conversion processes including combustion [31]. Moisture content in excess of 20% would result in considerable loss of energy required for water evaporation during combustion and such a fuel may not be stable in storage and affects the burning rate of the briquettes [32]. Tumuluru *et al.* [33] states that the moisture content that is less than 4%-5% will reduce the stability of briquettes thus making the briquette too dry and burn out at quick rate. This can also be represented in a positive correlation (r = 0.41; $P<0.05$) between %MC and BR of the samples (Table 3).

Other than water present in the charcoal the liquid which are easy to vaporize are called volatile matter (VM). Birwatkar *et al.* [34] recorded volatile matter values of briquettes produced from mango leaves, and saw dust with the values obtained ranging from 68.7% to 70.77%. From this experiment, it showed that % volatile matter of *Nypa* briquette was lower than *Eichhornia* briquette*,* with a significant difference ($P<0.05$) (Table 2). This also implies large moisture content in *Eichhornia* briquette. Large moisture content results in the formation of fumes but was observed that the moisture content of these briquettes were not less than 5% which made the briquette stable, and also were not very high preventing the formation of fumes as can be exemplified in a strong positive correlation (r = 0.97; $P< 0.05$) between VM and MC (Table 3). This corroborates the findings of Rezania *et al.* [17] in their production of briquettes using *E. crassipes*, empty fruit bunches of oil palm (palm oil mill residue) and cassava starch.

The analysis showed a significant difference ($P<0.05$)% Ash content between *Nypa* briquette and *Eichhornia* briquette (Table 2). The fewer the ash left after combustion, the greater amount of fixed carbon and combustible substance [17], this can also be represented in a negative correlation (r = -0.987; $P<0.05$) between the %Ash content and %FC and also a negative correlation (r = -0.986; $P<0.05$) between %Ash content and Specific heat of Combustion (Table 3). This implies that an increase in fixed carbon and Specific of combustion results to a decrease in the %Ash content.

The fixed carbon of a fuel is the percentage of carbon available for combustion [35]. Raju *et al.* [31] recorded fixed carbon content values of briquettes produced from paper, rice husk and coconut coir and had values that ranged from 17.9% to 18.6%. There was a significant difference ($P<0.05$) between the fixed carbon of *Eichhornia* briquettes which was lower than *Nypa* briquettes (Table 2). The high fixed carbon values of briquettes shows that the rate of cooking will reduce by its high release of heat [24]. This was rightly noticed in this present study in a negative correlation (r= -0.427 $P<0.05$) between %FC and BR; a positive correlation (r = 0.99; $P<0.05$) with SHC and (r = 0.43; $P<0.05$) with BT (Table 3).

The thermal analysis of ignition time of briquette samples has revealed a significant difference ($P<0.05$) between *Eichhornia* briquette lower than *Nypa* briquette (Table 2). The higher the moisture the lower the ignition as earlier reported by [24]. This can also be represented in this present research in a negative correlation (r = - 0.95; $P<0.05$) between ignition time and % MC (Table 3). This implies that an increase in moisture content decreased the ignition time. This also imply *Nypa* briquette with greater ignition time under low moisture content.

The burning rate of the samples showed a non-significant different ($P<0.05$) (Table. 2). High moisture content affects the burning rate of briquettes [32], this can be observed in the present study in a positive correlation (r = 0.41; $P<0.05$) between Burning rate and moisture content (Table 3). This implies that an increase in moisture content increased the burning rate of the briquettes. A high fixed carbon value of briquettes slows down the burning rate [24]. This is represented in a negative correlation (r =-0.43; $P<0.05$) between burning rate and % fixed carbon (Table 3). This implies that an increase in fixed carbon results to a decrease in the burning rate. This implies that *Nypa* briquette with high fixed carbon will have a low burning rate.

Burning time (how fast the fuel burns) is a factor that control the water boiling time [26]. This implies that the longer the water boiling time the lower the burning time of the briquettes. This can also be represented in a negative correlation (r =-0.32; $P<0.05$) between water boiling Test and burning rate in this present study (Table 3). The result as presented in Table 2 showed a significant difference ($P<0.05$) in the water boiling test of the samples.

There was significant difference ($P<0.05$) in the bulk density of the sample (Table 2). The higher the bulk density in briquettes, the higher the energy release and the burning time may also be longer [36]. This can also be represented in a positive correlation (r = 0.95; $P<0.05$) between Bulk density and Water boiling test, and a positive correlation (r = 0.46; $P<0.05$) between Bulk density and burning Time (Table 3). This implies that an increase in the bulk density increases the water boiling time, and an increase in the bulk density also prolonged the burning time of the briquettes.

There was a significant difference ($P<0.05$) in Specific heat of Combustion, by briquette of *Nypa fruticans* and *Eichhornia crassipes* with *Nypa* briquette higher. According to Aboagye [24], the high quality of heat energy produced is as a result of less content of moisture and high fixed carbon. This is a result of less % moisture content in the briquette, because moisture content hinders releases of heat. This was observations in the negative correlation (r =-0.91; $P<0.05$) between Specific heat of combustion and % Moisture Content, and a positive correlation (r = 0.99; $P<0.05$) between Specific heat of combustion and fixed carbon (Table 3). This implies that high moisture lowers the rate of heat released and high fixed carbon increases the rate of heat released. Low Ash content offers high specific heat of combustion [37], which was evident in the negative correlation (r = -0.91; $P<0.05$) between Specific heat of combustion and % Ash content. This implies an increase in Ash content to a decrease in Specific heat of combustion.

The measurement of shatter resistance of briquettes is essential in terms of its handling, transportation, storage and weather conditions as observed by Husain *et al.* [38]. There was non-significant difference ($P<0.05$) in the shattering index of the sample (Table 2). As observed by Husain *et al.* [38], the durability of briquettes is a major function of the moisture content and density. Also, the higher the moisture content, the lesser the durability of briquettes but density as well as FC and VM tends to enhance it. This can be observed in the present study as represented in a negative correlation (r =-0.07; *P<0.05*) between shatter resistance and %MC; and a positive correlation (r = 0.05; *P<0.05*) between shatter resistance and bulk density. This implies that as the %MC increased the shatter resistance decreased and as the bulk density increased the shatter resistance increased. Studies have also noted that briquettes produced from hydraulic piston processes have unit density lower than 1.00kg/cm^3 because of the limited pressure [33] which was the method used to produce these briquettes and also has an economic advantage, as low bulk density reduces the cost of briquettes transportation.

Table 2. *Briquette Characteristics (Mean ± SD) of E. crassipes and N. fruticans Biomass Feedstock.*

Parameters	***Eichhornia crassipes***	***Nypa fruticans***	**(P<0.05)**
Moisture Content	34.38 ± 2.21^a	11.83 ± 0.19^b	0.963
Ash Content	38.66 ± 1.86^a	28.99 ± 2.52^b	0.984
Volatile Matter	32.75 ± 1.00^a	24.27 ± 0.87^b	0.986
Fixed Carbon	29.84 ± 2.51^b	47.20 ± 2.38^a	0.966
Ignition Time	30.67 ± 3.06^b	50.67 ± 3.06^a	0.967
Burning Time	5952 ± 1862.40^b	7368 ± 2049.26^a	0.005
Burning Rate	$4.00 \times 10^{-6} \pm 17.0 \times 10^{-6a}$	$4.00 \times 10^{-6} \pm 2.00 \times 10^{-7a}$	1.000
Water Boiling Test	2080 ± 150.99^a	1340 ± 150.99^b	0.134
Bulk Density	$7.40 \times 10^{-5} \pm 2.12 \times 10^{-5a}$	$3.54 \times 10^{-4} \pm 6.6 \times 10^{-6b}$	1.000
Shatter Resistance	91.33 ± 4.29^a	91.63 ± 9.48^a	1.000
Specific Heat of Combustion	3141.66 ± 96.78^b	3620.86 ± 113.71^a	0.328

Values are expressed as Mean ± SD

Note: Similar superscript indicates an insignificant statistical difference at p-values >0.05, while different superscript indicates a statistically significant difference at p-values <0.05.

Table 3. *Pearson Correlations of the Briquette Characteristics.*

	M C	**A C**	**V M**	**F C**	**IT**	**B T**	**B R**	**WBT**	**BD**	**SR**	**SHC**
MC (%)	1										
AC (%)	0.910*	1									
VM (%)	0.973**	0.917*									
FC (%)	-0.950**	-0.987**	-0.957**	1							
IT (Kg/s)	-0.954**	-0.870*	-0.958**	0.937**	1						
BT (Kg/s)	-0.404	-0.399	-0.332	0.434	0.497	1					
B R (Kg/s)	0.405	0.492	0.503	-0.427	-0.238	0.316	1				
WBT (Cm^2/s)	0.920**	0.986**	0.923**	-0.985**	-0.891*	-0.323	0.437	1			
BD (g)	-0.987**	-0.934**	-0.967**	0.974**	0.976**	0.457	-0.324	-0.949**	1		
S R (%)	-0.073	-0.086	0.116	0.018	-0.127	-0.115	0.109	-0.123	0.054	1	
SHC (Kcal/kg)	-0.914*	-0.997**	-0.920**	0.986**	0.870*	0.341	-0.493	-0.995**	0.938**	0.117	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

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.

5. Conclusion

Briquettes gotten from *Nypa fruticans* and *Eichhornia crassipes* are good alternative source of energy which are eco-friendly, reduce deforestation and it's associated negative impacts and also means of regulating the speed of this invasive species on water ways. Based on the characterization of the briquette produced it can be concluded that: *Eichhornia* briquette had a lower bulk density compared to *Nypa* briquette which means that former is more economical in terms of transportation of briquettes due to it lighter weight. Based on the combustion properties *Nypa* briquette has a lower volatile Matter, and lower burning rate compared to *Eichhornia* briquette, thereby making *Nypa* briquettes have more heat emission on combustion compared to *Eichhornia* briquette. The results of proximate and mechanical analysis show that the *Nypa fruticans* has a better energy potential. Due to the low volatile matter released the ecosystem can be restored by the replacement of some harmful source of energy by these briquettes because the harmful gasses (carbon monoxide, sulfur) are not emitted into the atmosphere. It has been trapped out due to the process of carbonization. Based on these potentials are the following recommendations, viz: Treating the abundance of *Nypa fruticans* and *Eicchornia crassipes* and its relative significant heat contents as an opportunity to sensitize the local communities that it is indeed an alternative biofuel with economic and environmental advantage. The society should take advantage of increasing unemployed youth as a potential that can be trained to tackle the weed whenever its effects get beyond threshold. Educate the communities on the possible opportunities for controlling *Nypa fruticans* and *Eicchornia crassipes* that are within their scope of knowledge and resources to handle it. Generate monitoring systems to track specific infested areas and their seasonal movement. These efforts need to be integrated and cut across the communities that are faced with this alien invasion challenge of *Nypa fruticans* and *Eicchornia crassipes.*

Conflict of Interest

The author declares that they have no competing interests.

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