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Enhancing the Properties of Water Hyacinth Biomass Briquettes by Mercerization Process

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Authors' contributions

This work was carried out in collaboration among all authors. Author ECM undertook the conceptualization, and supervised. Author MCO undertook the methodology and prepared the manuscript. Authors AUBY and IAR supervised and provided the critical revisions of the manuscript, assist with the analyses, reviewing and editing. All authors read and approved the final manuscript.

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ABSTRACT

Water hyacinth is an aquatic plant that has a great reproductive potential. The propagation of water hyacinth in most water bodies have decimated the livelihoods of many and reduced the water quality, among other negative effects. Converting this invasive water hyacinth into briquettes will serve as a good measure for controlling its proliferation, and also as a strong strategy for the development of sustainable alternative energy sources. This study explored water hyacinth briquettes as alternative to the local wood fuels through mercerization process to enhance the qualities of a biomass briquette and encourage its use as a renewable energy source of fuel. The aim was to evaluate the combustion performance of treated water hyacinth (TWH) and water hyacinth (WH). After sample collection, preparation and treatment, the briquettes were produced using 20 g of starch prepared into slurry blended with 80 g of the sample to produce the briquettes. The proximate characteristics, physical properties, combustion properties, the morphologies and structural changes in the briquettes were determined. The results obtained showed that both samples have good energy potentials. The outcome indicates that the alkaline treatment removed

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the hemicelluloses in the biomass and in turn reduced the moisture content of the briquettes. Consequently, the physical and combustibility properties of the briquettes got improved. The calorific value also improved from (30.58 MJ/Kg) in WH to (34.22 MJ/Kg) in TWH, The scanning electron microscopy analysis showed a rough surface which enhanced bonding of the sample particles while the FTIR showed a structural change in the OH groups which indicates that the hemicelluloses have been removed.

Keywords: Water hyacinth; waste; briquetting; biomass; mercerization.

1. INTRODUCTION

Water hyacinth is a plant that originated from the Amazon basin; it is a highly invasive aquatic weed, mostly found in dams, swampy areas, lakes and irrigation channels in most tropical and subtropical regions. Its rapid growth rate enables it to easily adapt and compete with other aquatic plants causing a major threat to the aquatic environment [1]. This plant can cause blockage in water bodies, resulting to floods during heavy rains if it is not well managed and controlled.

Although water hyacinth is known by many people as a weed that is responsible for many environmental challenges, a lot of researches have been carried out in order to investigate its usefulness. Some of its useful application includes; biogas production, removal of heavy metals from aquatic systems, soil amendment after composting [2,3,4]. Also, there are lots of reported studies on the conversion of water hyacinth to charcoal dust via pyrolysis as a potential source for the production of locally needed fuels and briquettes production by mercerization process has not been documented [4].

Despite that water hyacinth biomass is capable of utilizing solar energy which makes it suitable for energy and heat generation, some properties of the biomass such as low density; low homogeneity and low calorific values can limit their direct use as fuels. In order to upgrade biomass residues for a variety of applications, their original form characterized by high moisture content, irregular shapes and sizes, low bulk density, difficulty in handling, transporting and storing, have to undergo some changes to make their use more economical [5,6]. Some of these limitations can be overcome through briquetting or densification of the biomass residues with binders for briquette production. During briquetting, the particulate fiber is compressed and compacted into blocks in a specific form, with lower volume and greater density and greater commercial value [7].

However, studies have also shown that biomass is composed of crystalline cellulose and amorphous non cellulose constituents that consist of lignin and hemicelluloses [8]. The non cellulose constituents are rich in hydroxyl groups because they are hydrophilic in nature. Hence they absorb moisture [9]. This suggests that chemical treatment can be performed on biomass fibers to remove or reduce the hydroxyl group [10,11,12]. Alkaline treatment with sodium hydroxide is one of the most chemical treatments for biomass fibers that can help to remove the hemicelluloses, lignin and surface impurities covering the inner cellulose components [13].

Thus, for a biomass briquette to have a better energy quality, better combustion performance, greater economic value, and ease of transportation and storage, the technique of alkaline treatment before briquetting can be employed. Hence, this study aims to evaluate the quality of briquettes produced by densification of water hyacinth, and those produced by mercerization before densification, in order to ascertain the type of production that will give better performance of fuel briquettes.

2. MATERIALS AND METHODS

The water hyacinth samples were obtained from a swampy area in Tudun Wada area of Aliero Local Government Kebbi State Nigeria as shown in Fig. 1. Sampling was systematically carried out in such a way that fresh water hyacinth samples were collected at different points within the swampy area. The collected samples were sun dried for three weeks to reduce moisture content and also to enhance the process of grinding the samples as shown in Fig. 2. After sun drying, the sample was grinded into powder form using a machine which was designed and fabricated to grind farm produce. Pulverization of the sample was necessary to increase the surface area of the components to enable strong particle bonding during briquetting. The starch used as a binding agent was purchased from Zuru market, and was used as purchased with no further modification as shown in Fig. 3.

Fig. 1. Fresh water hyacinth sample

Fig. 2. Dried water hyacinth sample

Fig. 3. Grinded sample of water hyacinth

2.1 Alkaline Treatment of the Biomass Sample

Research has shown that an alkaline solution, such as sodium hydroxide is very active for an effective reduction or removal of the non cellulose components covering the plant fibers [14]. The process is called mercerization. This mercerization also known as alkaline treatment involved soaking the plant fibers (water hyacinth sample) into a known concentration of aqueous sodium hydroxide solution at a given temperature for a given period of time. The alkali treatment of the sample was done with 5% sodium hydroxide. The 5% sodium hydroxide was used to soak the pulverized sample for 24 hours at room temperature [15]. This was done to modify the surface of the fiber, enhance fiber interface, and ensure good adhesion between the fiber particles by getting rid of hemicelluloses, certain amount of lignin, grease and wax covering the outer surface of plant fibers [16]. The soaked sample was rinsed several times to remove the sodium hydroxide sticking on the sample and dried under direct sunlight to remove the moisture content.

2.2 Production of the Briquettes

The summary of the procedure for briquette production is presented in Fig. 5. This involved four major steps, namely: preparation of materials used, mixing or blending of the prepared materials by hand, compaction of the materials using a developed briquetting machine, and sun drying of the briquettes to produce the finished products.

2.3 Determination of Physicochemical Properties

The physicochemical analysis of a briquette is a standardized analytical procedure used to quantify the main chemical and physical characteristics which affects briquette combustion characteristics [17].

2.3.1 Moisture content

The moisture content of the briquette samples was determined and calculated as ratio of the weight of moisture to the initial weight of sample [18] as expressed in percentage as given in equation (1) below:

$$percentage\ moisture = \frac{W_1 - W_2}{W_1} \times 100 \ldots\ldots\ldots\ldots (1)$$

Note: W_1 = weight of sample before oven drying, (gram)
W_2 = weight of oven dried sample, (gram)

2.3.2 Density

Density as physical property of the briquette is defined as structural packing of the molecules of the substance in a given volume. The density was determined using a weighing balanced in the laboratory by taking the weight of briquette sample and the dimension measurement using vernier caliper based on Adekunle *et al*., [18], the volume was evaluated using the relation $\pi r^2 h$ and the density was computed using equation 5.

$$Density\left(\frac{g}{cm^3}\right) = \frac{Mass}{Volume} \ldots\ldots\ldots\ldots\ldots \qquad (2)$$

Fig. 4. % NaOH treatment of water hyacinth

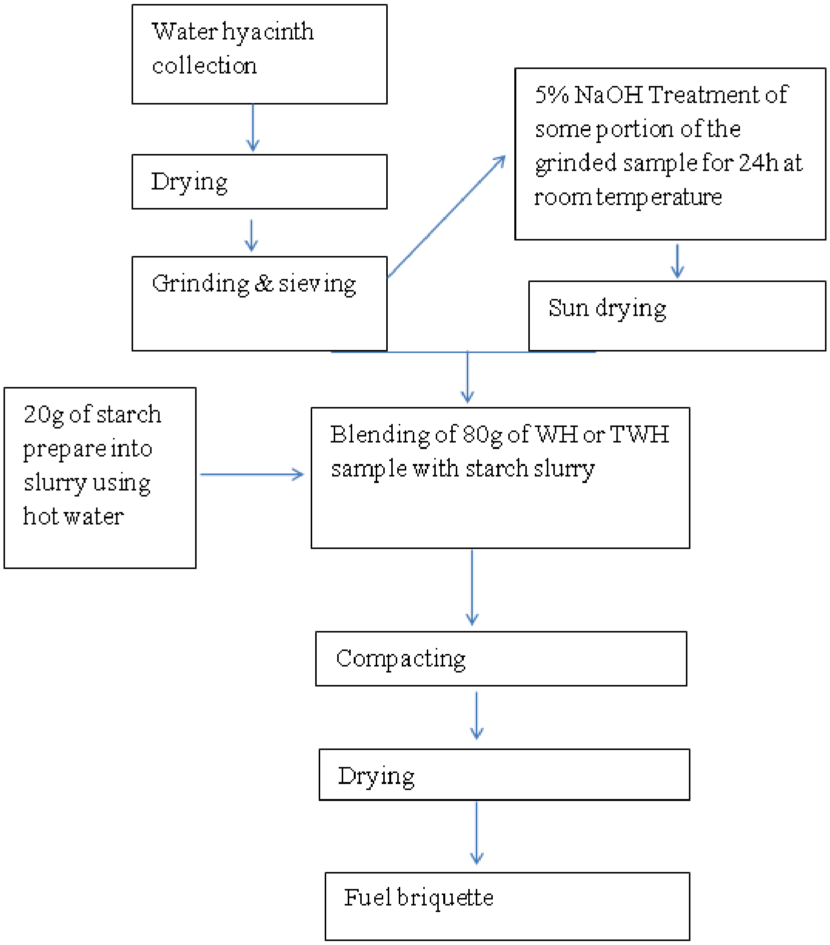

Fig. 5. Schematicproceduresfor the production of WH and TWH briquettes

Fig. 6. Produced briquette samples

2.3.3 Volatile matter

The briquettes percentage volatile matter content was determined using Lenton furnace. The residue of dry sample from moisture content determination preheated at 300°C for 2hrs to drive off the volatiles, the leftover sample was further heated at 470°C 2hrs, to ensure complete elimination of volatiles, just before the materials turns to ashes, and then cooled in a desiccator. The crucible with known weight and its content was weighed and expressed as the percentage weight loss, the Percentage volatile matter was computed using equation 2 [18].

$$Volatile\ matter\% = \frac{finalweight}{originalweight} \times 100 \ldots\ldots.(3)$$

2.3.4 Fixed carbon content

Fixed carbon was determined by using the data previously obtained in the proximate analysis and according to Garcia *et al.,* [19] using the formula in equation 4.

$$\%Fixed\ Carbon = 100 - (\%Ash + \%Volatilematter) \ldots (4)$$

2.3.5 Ash content

Ash content of the samples briquettes were determined using a furnace residue from fixed carbon determination were heated in a furnace at 590°C, for two hours and transferred into a desiccators to cool down the materials turned into white ash and weighed. Same procedure was repeated three time at 1hr interval until the weight was constant. The weight was recorded as the final weight of the ash, according on ASTM D1762-84, [20]. The percentage ash content was then calculated using equation 5.

$$Ash\ content = \frac{Weight\ of\ ash}{Original\ weight\ of sample} \times 100 \ldots\ (5)$$

2.3.6 Heating value

Leco AC-350 oxygen bomb calorimeter interfaced with a microcomputer was used to assess the heat values of the briquettes produced [21].

2.3.7 Compression test

A sample of the briquette was placed vertically in the compression test machine and a load was applied at a constant rate until the briquette failed by cracking [22].

2.4 FTIR (Fourier Transform Infrared Spectroscopy)

Infrared spectra of water hyacinth and treated water hyacinth were measured on AVATAR 330 Fourier Transform infrared (FT-IR) Spectrophotometer. The Fourier Transform Infrared Spectroscopy (FT–IR) was done by the Analytical Laboratory Services of Chemistry Department at Kebbi state University of Science and Technology Aliero.

2.5 Scanning Electron Microscopy

The micro-structure of the water hyacinth charcoal and the briquette considered to possess the best combustion characteristics were analyzed by Scanning Electron Microscopy (SEM) at the Umaru musa Yar'adua University Analytical Laboratory Katsina State. The samples were first transferred to capsules and coated with Palladium (Pd) at 30 mA and analyzed in a JEOL JFC-5510LV Scanning Electron Microscope.

3. RESULTS AND DISCUSSION

Moisture content is an important property that can greatly affect the combustion characteristics of the biomass [23]. It affects both the internal combustion temperature of the solid fuel briquette, due to endothermic evaporation, and the total energy that is required to bring the briquette up to the combustion temperature [24].

The results of the moisture content did not show much variation. But it appears that the moisture content of the briquettes tends to reduce slightly when the samples were alkalized or treated. Thus, the 5% moisture content recorded in water hyacinth (WH), may reduce the combustion properties of the briquette more than it will in TWH with 4.75%. This is because, during combustion, the briquette with more moisture will require more heat from the combusting fuel to vaporize, thereby reducing the heating value of the briquette fuel to a reasonable extent. This can also cause incomplete combustion and deposition of smoke on the stoves chimney, pots and pans used for cooking [25]. The result obtained is in contrast with report of Thiliza *et al.,*[26], who reported 10.6% of sesame stalk and 10.8% of rice husk respectively. According to Tamilvana, [27], high moisture content can also cause a delay in ignition time.

Almost all biomass, have high amount of volatile matter. Generally, biomass has a volatile content of around 70-86% of the weight of the dry biomass [28]. In this study, WH has 74.5%; this makes it a more reactive fuel than TWH with 70.5%. Hence, WH briquettes gave a much faster combustion rate during the Vaporization process. The higher percentage of volatile matter in WH is an indication that the ignition rate will be higher, and the briquette will burn faster than TWH. The low value of volatile matter observed in TWH could be due to the removal some of the impurities, oils, waxes and hemicelluloses by alkaline treatment.

As shown in Fig. 8, there was a decrease in the non-combustible component of the biomass that remained after combustion (ash content) of the alkalized briquettes. Evaluation of the calorific value content and ash content suggests that, the higher the briquettes ash content, the lower its calorific value. The results were in compliance with the reports of 7.68% of charcoal briquettes by Pinate and Dangphonthong, [29] and 6.65% of charcoal briquettes from Acacia melifera by Chukwuneke *et al*., [30]. Also, according to Channey,[12], when fuels with high ash content are burnt in cooking stoves, the flow of clean air into the cooking stove will be adversely affected if the residual ash is not frequently removed. Thus, low ash content is valuable, while excess ash causes trouble during burning because the ash is capable of blocking air from penetrating into the stove, thereby reducing the burning rate of such briquette unless the stove is often shaken to clear the ash during cooking. Also, ash can significantly influence the heat transfer to the surface of the fuel, as much as affecting the diffusion of oxygen to the fuel surface during char combustion [31].

3.1 Fixed Carbon

Fixed carbon gives significant amount of char that remains after the devolatisation process. These carbons are what react with oxygen to release heat [25]. Therefore, a high percentage of fixed carbon will enhance the heat value. Comparing the result obtained with other briquettes produced from Sugarcane Bagasse and Treated Sugarcane Bagasse, the fixed carbon of both WH and TWH is comparatively lower than those produced from SB and TSB in the work reported by Micah *et al*., [32]. The proximate analysis showed a higher fixed carbon and lower ash content of TWH briquettes. Hence the amount of ash produced can be correlated with the amount of fixed carbon and other combustible component of briquette.

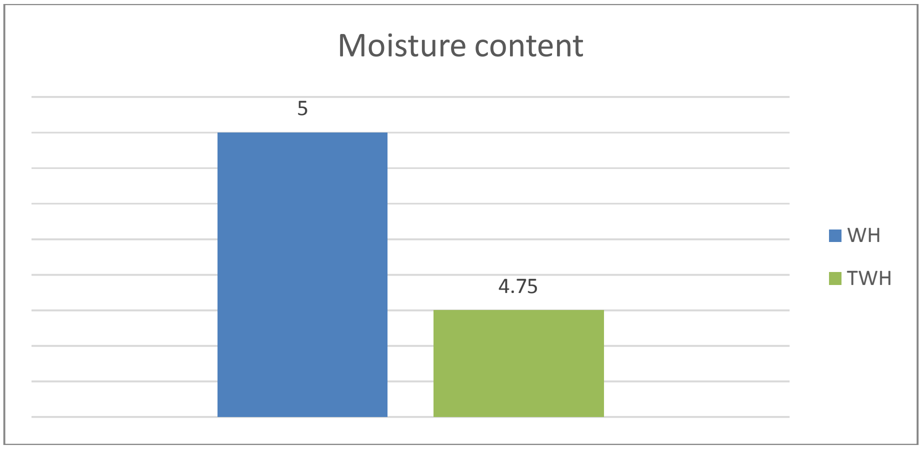

Fig. 7. Moisture content

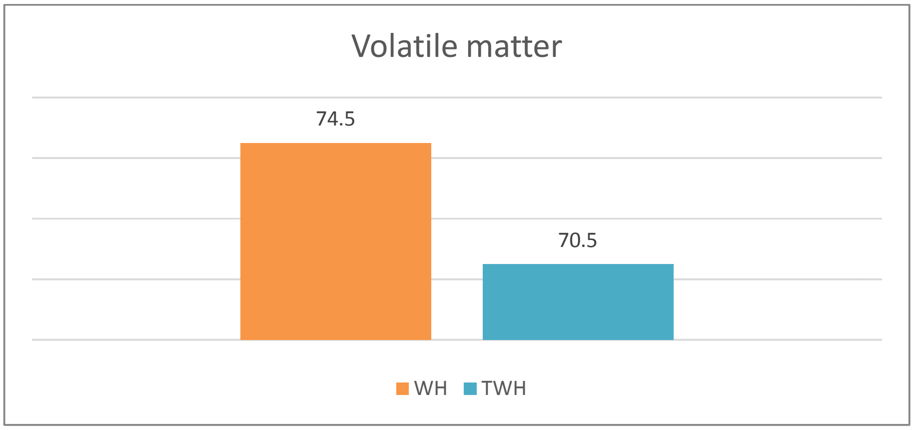

Fig. 8. Volatile mater content

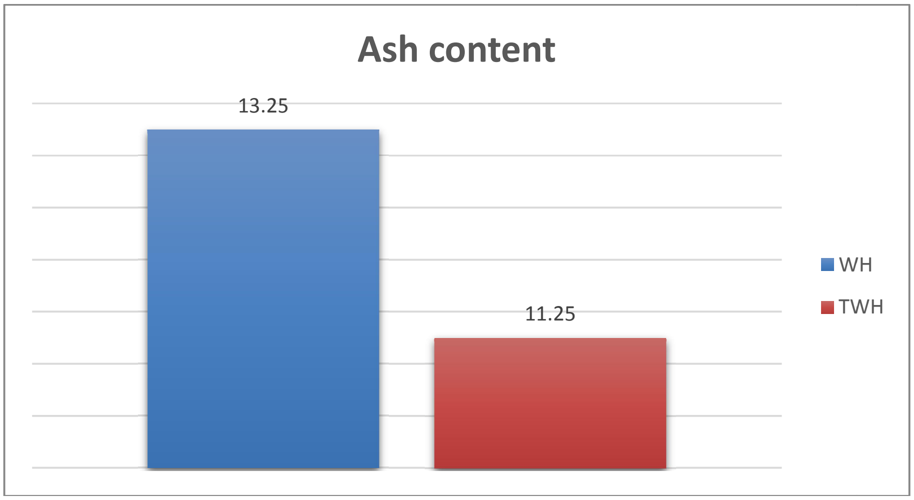

Fig. 9. Ash content

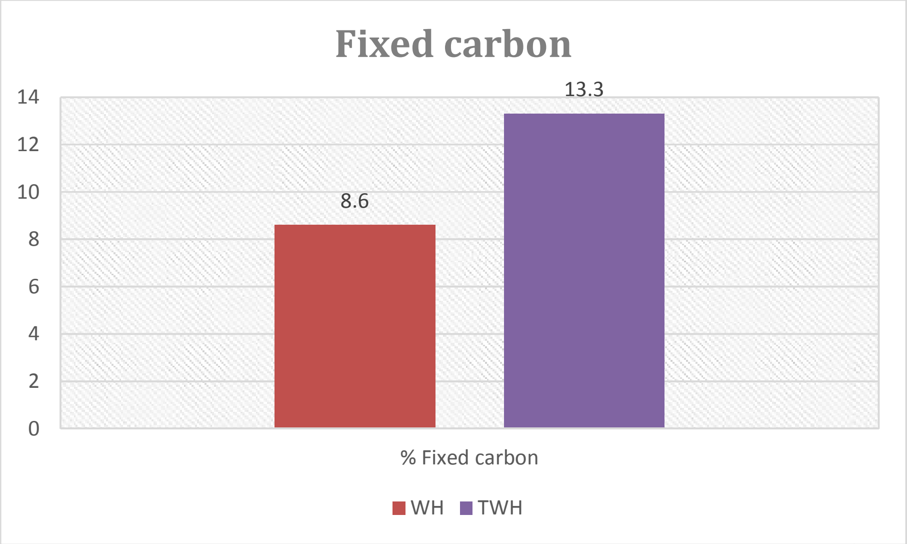

Fig. 10. Fixed carbon content

3.2 Calorific Value

The calorific value in this context can be described as the measure of energy released by the briquette fuel during combustion. Fixed carbon is one of the major contributors to the heating value of briquette charcoal [33]. Based on the results of this study, briquettes TWH have the higher heating value because of their high fixed carbon compared to WH. Apart from the fixed carbon, the low moisture and ash content observed in TWH could have also helped in increasing the calorific value. Therefore, it is also important to state that factors like quality of the briquette, high moisture and ash contents of the briquette could contribute to the decrease in calorific value and combustion efficacy. The results of calorific values were compared well with the result of charcoal briquettes with 25.92 MJ/Kg reported by Pinate and Dangphonthong, [29] and also in compliance with the result of carbonized rice husk briquettes with 25.78 MJ/Kg reported by Elinge *et al*., [34].

The density of briquettes plays a vital role in the determination of its value as fuel. The denser the briquette charcoal, the more heat it is likely to contain, and the longer the time the burning will last [3]. The densities of the briquette samples as shown below ranged from the highest in TWH (1.1811 kg/cm^3) to the lowest in WH (0.5821 kg/cm^3) due to lower value in moisture content obtained and compared well with density of notable biomass fuels of watermelon of 0.590 kg/cm^3 and 0.397kg/cm^3 and paper of 0.490 kg/cm^3 as reported by Ige *et al*., [35] and Aries, [36]. It is important to note that the TWH sample with the highest density had the highest calorific value as shown in the Fig. 11. More so, the denser the briquette, the easier for it to be transported, handled and stored [33]. This implies that TWH transported easily than WH without being damaged.

The results of compressive strength test shows that the TWH has the higher compressive strength more than WH. The result also shows that compressive strength improves as density increases and vice versa.

Figs. 14 and 15 shows the morphologies of WH and TWH samples at 1200× magnification. In Fig. 14 it can be observed that the surface texture of the untreated WH sample has a less destructive surface compared to the treated sample. This was due to the presence of surface impurities such as wax, pectin, and greases covering the WH fibers. In Fig. 15, there was presence of destructive surfaces on NaOH-treated WH sample. The destructive degree or roughness became more significant in TWH. This was attributed to the penetration of NaOH solution into the WH fibers. The NaOH breaks and removes the hydroxyl groups as well as the surface impurities in the amorphous non-cellulose constituents which increases the number of the crystalline cellulose exposed on the fiber surface. The removal of these non cellulose components enhanced fiber-matrix interfacial adhesion in the treated WH sample. Moreover, the removal of the hydroxyl groups in the treated WH sample reduced its hydrophilic nature and provides better compatibility of fiber to the matrix [13,37,38,11].

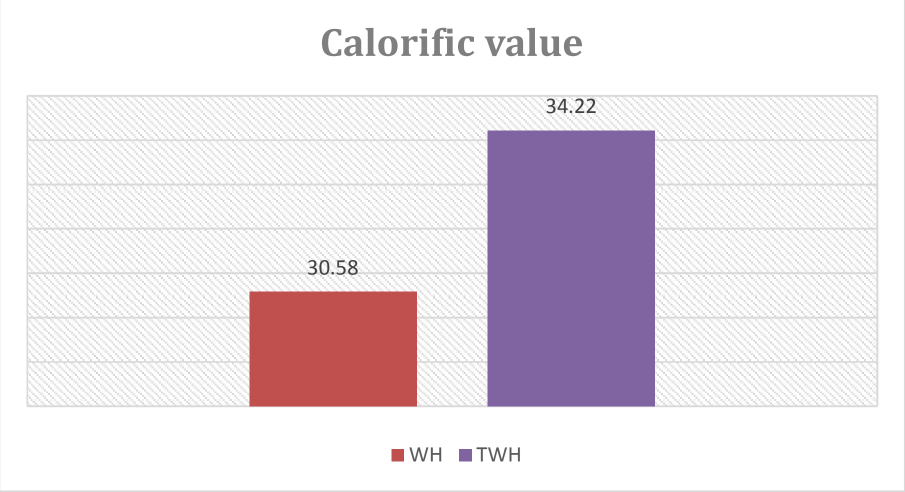

Fig. 11. Calorific value

Fig. 16 compares the FTIR spectra of untreated and alkali-treated samples within 500-4000 cm-1 wavelength region. The absorption bands at 3300 cm-1 correspond to the hydroxyl group (OH) in both the untreated and treated samples [13,39]. From the spectrum, it can be observed that the intensity of OH group in the TWH sample was significantly reduced after alkaline treatment; this implies that alkaline treatment broke the hydrogen bonding in the OH group, and cause a reduction in the intensity of the OH group in the NaOH-treated WH fibers.

The absorption around 2900 cm-1 for both the NaOH treated and untreated WH samples, is a C-H stretching in methyl or methylene group [21]. The absorption band at 1700 cm-1 in untreated sample corresponds to the carbonyl (C=O) stretching vibrations of carboxyl group in hemicellulose. A very close look at that the absorption band at 1700 cm-1 reveals that the C=O group disappeared in NaOH-treated WH samples. This is because the carboxyl group in the hemicelluloses was soluble in aqueous sodium hydroxide solution, this finding is in agreement with previous studies as reported by [40,13,41,42,43].

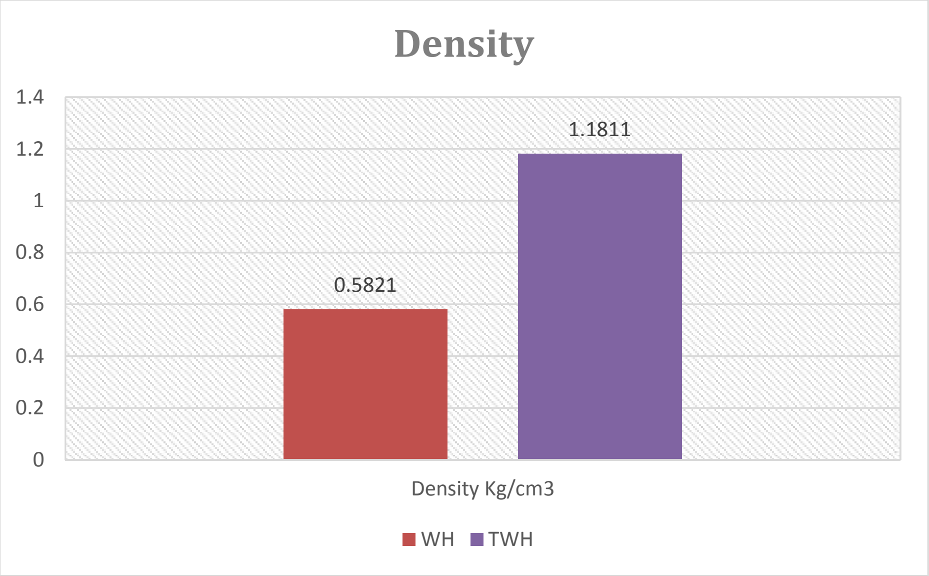

Fig. 12. Density

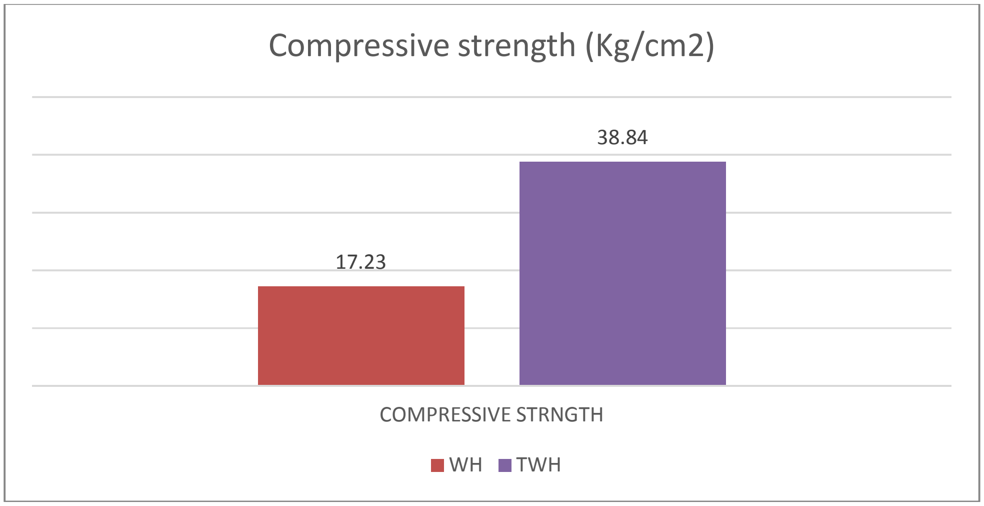

Fig. 13. Compressive strength value

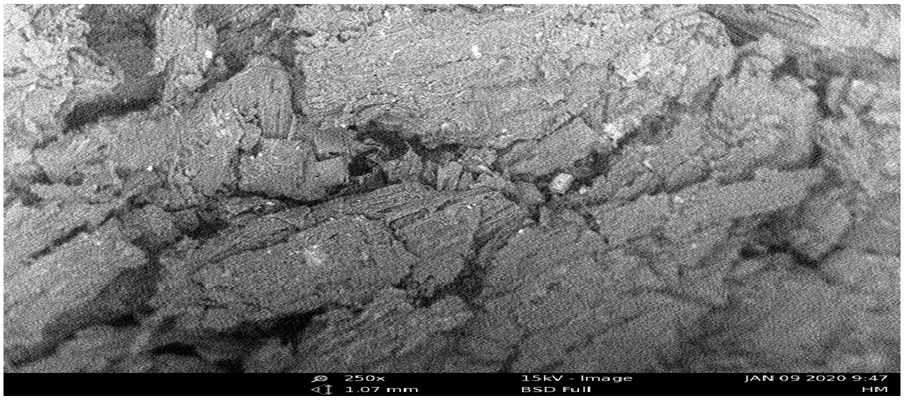

Fig. 14. Morphology of water hyacinth at 250x magnification

Fig. 15. Morphology of treated water hyacinth at 250x magnification

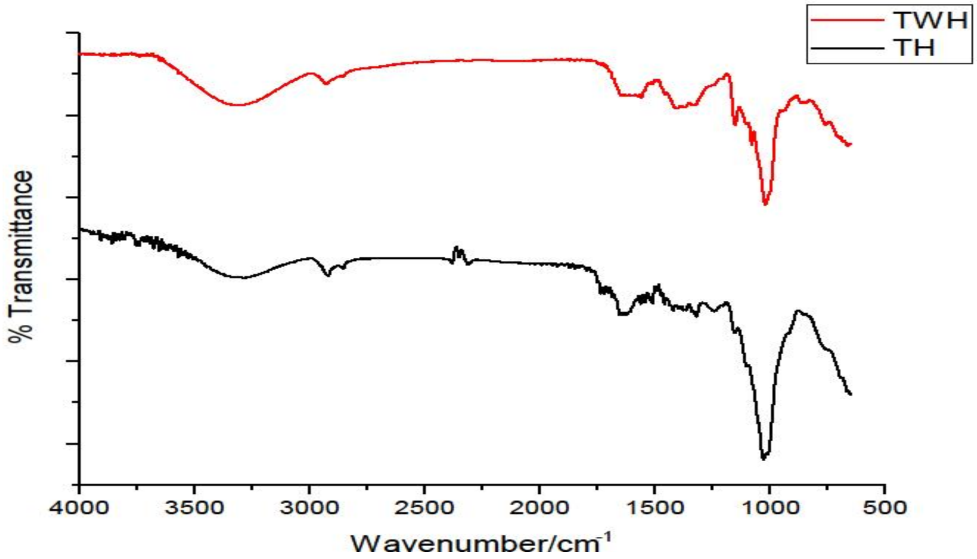

Fig. 16. FTIR spectrum of both the WH and TWH

The absorption bands at 1200, cm-1 correspond to the C-O stretching of the acetyl group of lignin in the untreated sample, while a decrease in the intensity of the band is observed in the alkaline treated sample. This implies that there was a slight decrease in lignin content of the NaOH-treated WH sample. However, the lignin did not disappear completely. This is because unlike hemicellulose is much more difficult to remove lignin by alkalization [40, 43].

The absorption bands around 1000 cm-1 for the untreated sample, and NaOH treated sample, could be attributed to C-O stretching in cellulose, hemicelluloses and lignin [44].

4. CONCLUSIONS

This study was carried out to enhance the energy properties of water hyacinth briquette by mercerization for better combustion. Alkaline treatment of WH sample removed the amorphous non cellulose components of the sample. This reduced the hydrophilic tendencies of the sample, increased the surface roughness of the sample, enhanced the matrix fiber interface and ensures a good adhesion of the fibers. The removal of hemicelluloses reduced the moisture content of the briquette. Increase in the surface roughness of the sample, matrix fiber interface and adhesion improved the compressive strength and density of the briquette. Density of a briquette plays a vital role in the determination of its value as fuel, because the higher the density of a briquette, the longer the time the burning will last and the more heat it is likely to produce. The results obtained in this study showed that TWH which had a higher density (1.1811 kg/cm^3) than WH (0.5821 kg/cm^3), also had a higher calorific value. Therefore, it can be concluded that alkaline treatment of biomass wastes would improve its combustion, physical and mechanical properties and can be used for domestic purpose and small scale industries.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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