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RESEARCH ARTICLE

BIOETHANOL AND BRIQUETTE PRODUCTION AS AN ALTERNATIVE CONTROL MEASURE OF WATER HYACINTH ON LAKE VICTORIA

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ABSTRACT

The processing of water hyacinth is one of the predominant energy sources for bioethanol and briquette production, however, its technological development in developing countries is still limited. This study investigated the physico-chemical properties of water hyacinth as well as the energy characteristics of bioethanol and briquettes. Fresh water hyacinth samples were collected and analysed for lignin, cellulose, hemicellulose, dry matter, ash content, organic matter and organic carbon contents. Bioethanol was produced through acid (0.5 M), alkali (0.5 M) and yeast saccharification (20g) pretreatment, followed by fermentation and distillation of crude ferment. Bioethanol was analysed for brix, pH, percent yield and calorific value. Briquettes were produced by drying freshwater hyacinth, carbonizing and compacting of biochar with cassava starch, anthill soil and cow dung binders. The briquette quality was determined using proximate and ultimate analysis. The physical-chemical analysis results for lignin content, cellulose content, hemicellulose, dry matter, ash content, organic matter and organic carbon percentage contents were 20.20%, 24.63%, 27.87%, 15.13%, 3.80%, 96.63% and 96.35% respectively. The percentage bio-ethanol yields were 29.5 % acid hydrolysed ferment, 18% alkali hydrolysed ferment and 20.5 % enzyme hydrolysed ferment. The calorific values of bioethanol and briquette samples of cassava starch, anthill soil, cow dung and no binder were 26.4 MJ/kg and 8.061 MJ/kg, 2.076 MJ/kg 9.034 MJ/kg, 7.174 MJ/kg respectively. It was concluded that bioethanol produced from water hyacinth was of good quality and fit for use as a cooking fuel. The briquettes produced using cow dung and cassava starch binder exhibited higher heating values compared to those of anthill soil binder and no binder; therefore, they can be used as an alternative to traditional fuels.

KEYWORDS

Bioethanol, Biomass, Briquettes, Water Hyacinth

1. INTRODUCTION

Uganda is still predominantly dependent on biomass that contributes 88% of the total primary energy consumed through firewood, charcoal and crop residues. The widespread dependence on biomass energy resources for cooking has resulted into rapid deforestation estimated at 0.8% per annum in 2016, which is equivalent to a loss of about 50,000 hectares of forest per year. The estimated total annual demand for woody biomass of 53 million tons in 2013 exceeded the sustainable annual supply of 26 million tons, creating a huge deficit (MEMD, 2019). Thus, the use of other efficient biofuels including briquettes, biogas and bioethanol derived from agricultural residues, forestry residues and Water Hyacinth (WH) can be a pre-requisite.

WH is an aquatic biomass plant that floats freely on the surface of fresh water and has been proven to be a resource to produce biofuels. The presence of cellulose, hemicellulose and lignin in water hyacinth makes it a viable biofuel feedstock (Ruan et al., 2016). In Uganda, WH is in abundance and has created vast disturbance in navigation and power generation on Uganda's waters especially Lake Victoria. Investment has been directed towards the control of water hyacinth through mechanical and biological techniques, but none has been successful. A group researchers investigated the possibility of using WH for generating biogas energy using a laboratory set up (Edimu, et al., 2018). For effective control of the weed, other studies have to be studied for its possibility as an alternative energy source, especially briquettes and bioethanol.

Various research studies have been performed that sought to utilize WH for bioethanol and briquettes production, including, the positive use of the weed in the generation of farm fertilizer, production of bioethanol generation of biogas energy have been reported worldwide (Shahabaldin et al., 2016; Dennis, et al., 2018; Madian, et al., 2019; Bote et al., 2020). The lignocellulose in WH can easily be bio-converted by enzymatic means to fermentable sugar, thus resulting in an enormous amount of utilizable biomass for bioethanol production. Najmudeen, Febna, Rojith, & Pariyappan, investigated the elemental composition and structural characterization of biochar from WH using CHNS analyser, FTIR, XRD, and SEM, respectively (Najmudeen et al., 2019). Optimum pyrolysis conditions were finalized and pyrolysis at 300°C for 30 minutes was used for the production of sufficient quantities of biochar for further experiments.

In a study by WH was chopped, sun-dried and pulverized to a particle size of <5 mm and mixed with various binders (Eucalyptus globulus leaves powder, molasses and phytoplankton scum) (Onyango et al., 2020). The binders were appropriately prepared and added to WH at the ratios of 10%, 20% and 30%. Binders help improve the calorific values of

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briquettes Borowski, Stępniewski, & Wójcik-Oliveira, enhance bonding and formation of strong and more stable briquettes, which are easier to handle, transport and store (Borowski, et al., 2017; Asamoah et al., 2016). The quality of briquettes was evaluated using compressed density, relaxed density, water resistance, durability and caloric values (CV) parameters.

One of the problems commonly encountered in the use of briquettes from biomass wastes is their difficulty to ignite. A group researchers presented that the physicochemical properties are a primary reference for the quality of energy contained in the fuels produced from WH (Sukarni, et al., 2019). Moisture content, fixed carbon, ash, volatile content are some of the critical properties that affect ignition/ calorific value of the briquettes and bioethanol. Therefore, this study examines the potential of using WH as an alternative material for briquettes and bio-ethanol production. In addition, the study characterizes the optimum ratio of anthill soil, cassava starch and cow-dung as binders in order to produce fuel briquettes with a high calorific value. The physical, chemical, combustion and energy characteristics of the briquettes were also determined. Regarding production of bioethanol from WH, this study focuses on determining the calorific value and burning characteristics of the bioethanol.

2. METHODS

2.1 Sample Collection

Briquettes and bioethanol were processed from fresh WH samples collected from Lake Victoria in Uganda particularly on Port Bell and surrounding areas. Whole WH plant was collected from the lake and then the leaves and stems cut off from the root system. Cow-dung and Ant-hill soil were collected from the College of Veterinary and Biodiversity grazing unit of Makerere University.

2.2 Physical and Chemical Properties of Water Hyacinth

Experiments to determine the physical and chemical properties of WH included parameters such as lignin, cellulose and hemicellulose, dry matter, ash content, organic matter and organic carbon contents. Lignin, cellulose and hemicellulose contents were investigated using H_2SO_4, alkali and Yeast treatment. Ash content was determined on fresh dry basis (dry-ashing).

2.3 Determining the Physical and Chemical Properties of Water hyacinth

2.3.1 Extraction of lignin, Cellulose and Hemicellulose

Water hyacinth stems and leaves were washed with water. The samples were weighed and analysed in Triplicates for cellulose, hemicelluloses, lignin, total reducing sugars and ash content using the method developed according to (Ververis, 2007).

2.3.2 Determination of Lignin Content

Sub-samples (10 g each) of freshwater hyacinth were boiled with 5 mL of 70% H_2SO_4 solution for 30 minutes in order to hydrolyse the cellulose and hemicellulose. The suspension remaining after the treatment was filtered through a Whatman filter paper and the solid residue dried at 100 °C for 24 hours and weighed (W_1). The residue was then transferred to a pre-weighed dry porcelain crucible and heated in an oven at 100^oC for 30 minutes. On cooling, the sample was weighed (W_2). Acid insoluble lignin was then calculated by the difference (W1 - W2). The lignin in the samples was calculated using Equation 1 (Ververis, 2007).

$$\%\, lignin\ content = \frac{lignin\ mass (W1 - W2)\ (g)}{dry\ mass\ of\ water\ hyacinth}\ X\ 100 \tag{1}$$

2.3.3 Determination of Cellulose Content

The filtrate from the H_2SO_4 treatment that contained the sugars released from cellulose and hemicellulose was thoroughly stirred and homogenized. Glucose (C_1) and reducing sugar (C_2) concentrations in the filtrate were determined according to a glucose oxidase–peroxidase assay kit and the DNS method respectively. The cellulose content in the starting material was then calculated using Equation 2:

$$\%\, cellulose\ content = \frac{W_1}{W_2} \times \frac{0.9}{0.96} \times C_1 \times \frac{V}{M} \times \gamma \times 100 \tag{2}$$

Where 0.9 is the coefficient that results from the molecular weight ratio of the polymer and the monomer hexose. The saccharification yield was taken as 0.96, C_1 as the glucose concentration (g/L), V the total volume of sugar solution (L), M the fresh weight of the water hyacinth sample (g) and ɣ dilution of the sample. (Ververis, 2007).

2.3.4 Determination of Hemicellulose Content of the Fresh Water Hyacinth

The hemicellulose content was calculated using Equation 3.

$$\%\, hemicellulose\ content = \frac{W_1}{W_2} \times \frac{0.88}{0.93} \times (C_2 - C_1) \times \frac{V}{M} \times \gamma \times 100 \tag{3}$$

Where 0.88 is the coefficient that results from the molecular weight ratio of the polymer and the monomer pentose, 0.93 is the saccharification yield of xylane to xylose, C_2 is the determined reducing sugars concentration (g/L) from the DNS method, C_1 the glucose concentration (g/L) from above, V is the total volume of sugar solution (L), M is the dry weight of the water hyacinth sample (g) and α the dilution of the sample (Ververis, 2007).

2.3.5 Determination of Dry Matter

Three 100 g samples of freshwater hyacinth was weighed into new Aluminium plates and each placed in an oven at 105 °C for 24 hours until a constant mass was obtained. The percentage of dry matter was then determined using Equation 4 (Ververis, 2007).

$$\%\, dry\ matter = \frac{Dry\ mass\ of\ water\ hyacinth}{Fresh\ mass\ of\ water\ hyacinth}\, x\ 100 \tag{4}$$

2.3.6 Determination of Ash Content, Organic Matter and Organic Carbon

Ash content was determined on fresh dry basis (dry ashing). Oven dried samples (5.0 g) were placed in a muffle furnace at 550 °C for 8 hours and the ash formed was weighed as the ash content. The percentage of ash content, organic matter and organic carbon were determined using Equations 5, 6 and 7 as proposed by (Netai et al., 2016).

$$\%\, Ash\ content = \frac{Ash\ mass\ of\ water\ hyacinth}{Dry\ mass\ of\ water\ hyacinth}\, x\ 100 \tag{5}$$

$$\%\, Organic\ matter = \frac{Dry\ mass\ of\ water\ hyacinth - Ash\ mass\ of\ water\ hyacinth}{Dry\ mass\ of\ of\ water\ hyacinth} X100 \tag{6}$$

$$\%\, Organic\ carbon = (\%\, Organic\ carbon\ of\ water\ hyacinth)/1.724 \tag{7}$$

Where 1.724 is the van Bemmelen factor (that is, Organic matter contains 58% OC)

2.4 Bio-ethanol Production

2.4.1 Pre-treatment of the Water Hyacinth using Acid Saccharification of the fresh Water Hyacinth

Water hyacinth samples of 200 g were added to a conical flask and 25 mL of 0.5 M of Sulphuric acid was added followed by 200 mL of distilled water. The solution was filtered using Whatman filter paper of 0.45 µm. The filtered sugar solution was clarified with quick lime (calcium oxide) to ensure that the sugar solution was free of sediments. The clarified sugar solution was then fermented using prepared inoculum of saccharomyces cerevisiae and glucosidase enzyme recipe.

2.4.2 Alkali Saccharification of the Fresh Water Hyacinth

Water hyacinth samples of 200 g were added to a conical flask and 25 mL of 0.5 M of sodium hydroxide solution was added followed by 200 mL of distilled water. The solution was filtered using Whatman filter paper of 0.45 µm. The filtered sugar solution was clarified with quick lime (calcium oxide) to ensure that the sugar solution was free of sediments. The clarified sugar solution was then fermented using *Saccharomyces cerevisiae.*

2.4.3 Fermentation of the Water Hyacinth Sugar Solution using the Prepared Yeast Inoculum

The clarified saccharified water hyacinth solution from the acid and alkali saccharification was then measured for sugar concentration using a Refractometer to ascertain the fermentable sugars prior to fermentation. The clarified solution was fermented with 25 mL of the yeast inoculum recipe for 24 hours in fermentation bottles. In order to optimize the fermentation process, the clarified sugar solution was adjusted to pH 4.0 and kept between 25 °C and 30 °C and the microbial inoculum concentration maintained at optimal levels. The fermentation bottles were also sealed tightly to prevent oxygen from interfering with the anaerobic respiration of the microbes.

2.4.4 Recovery and Distillation of the Bio-ethanol from Crude Ferment

The crude ferment was distilled in the Rotary Distiller using IKA – fractional distillation column. The 200 mL of the crude ferment were added in the distilling flask and distilled at 77 °C for 1 hour. The bioethanol was lit in an ethanol stove to determine whether it was combustible and ready to be used.

2.4.5 Determination of % Brix using Refractometer

Water hyacinth samples (100 g) were weighed and dried. The dried plant material was hydrolysed using acid and alkali. The solution was filtered and the percentage brix read using a Refractometer. Sample drops were placed on a clean glass prism of the Refractometer measuring surface using plastic pipette. Looking through the eyepiece while holding the Refractometer up to a natural light source, the eye piece was twisted to adjust the focus. The reading where the contrast line crosses the scale was then recorded at the percentage brix value (Garriga et al., 2017).

2.4.6 Determination of pH of Bioethanol

pH of the bioethanol was determined using Thermo-Scientific Orion 3 Star pH bench top model pH meter. The PH meter was calibrated using buffer of pH 7.0. The pH meter was placed in the bioethanol sample and the displayed pH value read. The process was repeated thrice for each sample after rinsing the pH meter in tap water.

2.4.7 Percentage Bioethanol Yield

Percentage yield of bio-ethanol was determined using Equation 3.8 (Nuwamanya et al., 2012).

$$\% \, yield = \frac{Volume\ of\ recovered\ bioethanol}{Volume\ of\ saccharified\ sugar\ solution} X \; 100 \tag{8}$$

2.5 Briquette Production

Fresh water hyacinth weighing 200 kg was collected from Lake Victoria's Port Bell. The water hyacinth was sun dried for 7 days to 8.27 kg (Figure 1). This was followed by carbonisation and compression in the presence of a binder and water.

Figure 1: Drying of water hyacinth

2.5.1 Carbonisation of Water Hyacinth

An institutional firewood stove was used in the carbonisation of water hyacinth at a temperature of 300 °C. Kerosene was sprinkled on the water hyacinth and lit to start the carbonisation process. The stove was then covered to limit the oxygen intake and occasionally checked after 15 minutes from the start of char formation. Water was poured into the stove to optimise the temperature. The temperature was measured using an Infra-red Thermometer (Testo 835-T2, Germany). The char was removed and the stove lit afresh to complete the carbonisation process of the water hyacinth there in.

2.5.2 Compaction of Char into Briquettes

The binders used in the briquette production included cassava starch, ant-hill soil and cow dung. Cassava flour (1 kg) was first boiled in water to form 2 kg of cassava starch binder. The binder was then added to 1kg of char. Samples from the different char- binder mixtures were deposited in the holder of a manual briquette making machine (Piston Press) and pressed into cylindrical briquettes.

2.5.3 Briquettes with Anthill Soil as a Binder

Anthill soil (0.6 kg) was mixed with 0.2 litres of water. The mixture was then added to 1.6 kg of char. The mixture was deposited in the holder of a manual briquette making machine (Piston Press) and pressed into cylindrical briquettes.

2.5.4 Briquettes with Cow-dung as a Binder

Fresh cow dung (0.7 kg) was directly added to 0.3 kg of char (Figure 3.12). The mixture was deposited in the holder of a manual briquette making machine (Piston Press) and pressed into cylindrical briquettes.

2.5.5 Briquettes Formed with Water Hyacinth Only (No Binder)

Char (water hyacinth with no binder) was mixed with water and the mixture was deposited in the Piston press machine to make cylindrical briquettes.

2.6 Energy Properties of Briquettes and Bio-Ethanol Produced from Water Hyacinth

2.6.1 Determination of Bio-Ethanol Quality

Bio-ethanol samples of 2 mL were poured in capsules on which the bomb calorimeter thread was tied and placed in a crucible. The crucible was then placed in the Bomb calorimeter which was started. Combustion of the thread in turn combusted the bioethanol and displayed the calorific value of the bioethanol.

2.6.2 Determination of Briquettes Quality

The Thermo-Gravimetric Analyser (TGA) was opened, its crucibles cleaned and weighed. Prior to analysis, the samples were homogenised using a ball mill Homogeniser Retsch PM 100 model. Briquettes without a binder were homogenised for one minute and 20 seconds while those with ant hill soil, cow dung and cassava starch were homogenised for 46 seconds, 28 seconds and one minute 20 seconds respectively. A minimum of 1100 mg of homogenised samples were weighed in the crucibles and loaded into the TGA machine. The crucible lids were inserted. This was followed by opening the nitrogen and oxygen cylinders. The analysis started from the moisture stage through the volatile stage to the ash stage.

2.6.3 Determination of the Calorific Value of the Briquettes

Briquette samples of weights between 0.8-1.1g were poured in a crucible with a Bomb Calorimeter thread and placed in the Bomb Calorimeter following the ASTM-D5865 standard. Knowing the heat capacity of the calorimeter, the heat released from the combustion of the samples was determined from Equation 9:

$$\Delta U_b = C_v \Delta T \tag{9}$$

Where ΔU_b is the change in internal energy of the bomb calorimeter and its contents,

C_v is the heat capacity of the calorimeter, ΔT is the temperature change.

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Properties of Water Hyacinth

The results of the physical and chemical characterization of the WH from Lake Victoria are presented in Figure 2.

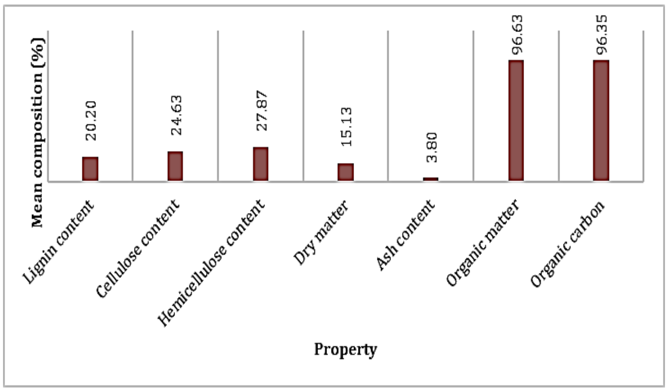

Figure 3: Composition Analysis of Water Hyacinth

Figure 2 reveals that the water hyacinth feedstock generally contained a high amount of organic matter, organic carbon and reducing sugars. Cellulose, hemicellulose and lignin were in moderate proportions while dry matter and ash content were low.

3.1.1 Percentage Dry Matter

The dry matter is slightly higher; an indication of higher fiber content (lignocellulose residues) in the water hyacinth on dry basis. According to some study, higher dry matter content indicates the the WH is rich in nutrients (Su et al., 2018). FAO in their study reported that the dry matter generally varies between 5 % – 9 %, which is lower than that for this study (FAO, 2021). According to Akinwande, Mako & Babayemii (2013),the dry matter of WH was found to be 9.84 %. According to the some researchers the variations in percentage dry matter content depends directly on the water mineral concentrations where the hyacinth grows (Akinwande et al., 2013).

3.1.2 Percentage Ash Content

The ash content obtained is very low in comparison with other physical properties and is within the range as reported by other Authors. According to ash content is influenced by the inorganic elements which are a non-flammable part of biomass (Liu et al., 2018). Reales- in their study determined that the ash content of WH is 1.614 % and that the differences found may be because the nutritional conditions of habitats affected the metabolic processes of the plant, resulting in different chemical characterizations (Alfaro et al., 2013). In other studies by the ash content was determined to be between 1.2 % and 2.0 % (Ruan et al., 2016; Ververis et al., 2007).

3.1.3 Percentage Organic Content

Figure 2 reveals that organic matter is the highest physical property in WH with values ranging between 96.4% - 97.2 %. It is also observed that the percentage organic carbon obtained for this study is higher than that determined by other Authors. The difference could have been attributed to the high eutrophication rates due to human activities that release the non-point fertilizers from the farmlands around Port Bell and the Kyaggwe side between Luzira and Mukono separated by only 7 km distance from the farm lands. Netai, Kugara & Zaranyika reported that the percentage organic matter of WH is 81.57 % which is lower than the one got from this study (Zaranyika, 2016). A group researchers in their studies reported that organic matter of water hyacinth is 74.3 % and 83.65 % respectively (Abdelhamid and Gabr, 1991; Chanakya et al., 1993). Accordingly to a study also determined the percentage organic matter to be 90.8 % (Nyananyo et al., 2007).

3.1.4 Percentage Organic Carbon

The percentage of organic carbon is one of the highest physical properties in WH, an indicator of higher levels of carbon stored in the WH. High carbon content indicates that the WH will generate relatively better calorific values, however this can be hampered by other factors such high ash content and oxygen levels. The percentage organic carbon obtained for this study is higher than that determined by others. The difference could have been attributed to the location of the site from where the water hyacinth was collected. Port Bell, Luzira is a highly eutrophified catchment area with non-point and point pollution from both Agricultural and Industrial waste, and agriculture fertilizers like NPK, phosphorous and nitrates. Netai, Kugara & Zaranyika determined that the percentage organic carbon of WH is 47.31 % (Netai et al., 2016).

3.1.5 Percentage Lignin Content

The percentage of lignin in WH obtained in this study was very low compared to the compositions of cellulose and hemicellulose contents. The average lignin content in Figure 2 is comparable to that reported by which ranged between 12 – 26 % (Cheng, et al., 2014; Bani-Taslim and Iriany, 2015). According to the high content of lignin present in the water hyacinth inhibits the utilization of cellulose and hemicellulose in the hydrolysis process leading to low percentage of cellulose and hemicellulose content (Reales-Alfaro at al., 2013). This is also evidenced by studies done by where percent lignin content obtained was very low i.e between 3.6 % - 5.5 %, with higher percent cellulose and hemicellulose contents of between 16.4 %, -18.4 and 42.8 %, -49.2 % respectively (Rezania et al., 2018; Kumar et al., 2009).

3.1.6 Percentage Cellulose Content

The WH is rich in cellulose content and therefore provides greater fibrous and spongy appearance of the outer and inner matrix of the WH. This prediction was supported by other previous studies that reported the natural composition of water hyacinth lignocellulose component. Some researchers reported the cellulose composition in water hyacinth was in the range of 18.2 – 19.7%. Other studies reported percentage Cellulose Content of between 17 % and 31 % (Bardant et al., 2018; Cheng et al., 2014; Bani-Taslim and Iriany, 2015).

3.1.7 Percentage Hemicellulose Content

The WH is also rich in hemicellulose content, an indication of higher fermentable sugars contained in it. This could have been attributed to the fact that hemicelluloses are broken down to provide the energy necessary of translocation and transport of other nutrients in the vascular bundles (xylem and phloem) of the water hyacinth. A group researchers had the same results as this study and indicated that lower hemicellulose (19.6 %) and higher residual cellulose (35.4 %) contents indicate that acid treatment had removed most of the hemicellulose and exposed the cellulose for further enzymatic hydrolysis for bioethanol production (Arpan, et al., 2016).

It was observed that acid hydrolysis seemed to accomplish a considerably higher improvement in pre-treatment than alkaline hydrolysis. This is because acid pre-treatment increases more of the WH's active surface area and pore size. This was also observed by a study conducted by Kumar, Singh, and Ghosh that indicated that acid pre-treatments are effective methods used for water hyacinth for dissolving hemicellulose and retaining most of the cellulose (Kumar et al., 2009). The results also showed that hemicellulose was predominant in WH which is in agreement with the previous data from (Ganguly et al., 2013; Yan et al., 2015). Differences in the composition of WH might originate from its source, the growth state of the WH, the time of harvesting, and the nutritional conditions in the plant habitat (Reales-Alfaro et al., 2013); Rezania et al., 2017).

3.1.8 Fermentable Sugars (Percentage Brix)

The acid hydrolysed solution contained the highest sugar content of 19% brix, this was because the acid broke down all the lignocellulosic residues to sugars since it acts strongly compared to alkali hydrolysis which gave 16.7% brix of sugar solution. The enzyme hydrolysis gave relatively a lower value of 18.7%brix because enzymes are affected by several factors such as enzyme concentration, pH of medium, substrate concentration and end –product inhibition and other factors that control all enzyme kinetics like Affinity and Velocity of both forward and backward reactions.

3.2 Briquettes and Bioethanol from Water Hyacinth

3.2.1 Bio-ethanol Production

The results of % bio-ethanol yield and pH after pre-treatment of WH with acid and alkali are presented in Table 1.

Table 1: Bio-Ethanol Quality

Bio-Ethanol Quality Parameter	H1	H2	H3
Reducing sugar content in g/g	597.30	481.30	586.10
% bio-ethanol yield	29.50	18.00	20.50
pH	4.50	9.70	6.90

Where: H1= acid hydrolysed, H2= alkali hydrolysed and H3= Enzyme hydrolysed

From Table 1, reducing sugar content in g/g and % bio-ethanol yield by each type of pre-treatment method was both in reducing order of H1, H3 and H2. The highest reducing sugar content in g/g obtained by acid hydrolysis has the highest % bio-ethanol yield. It can be concluded that the reducing sugar content in g/g and % bio-ethanol yield had a linear correlation that means higher sugar concentration would produce higher ethanol. A group researchers reported that reducing sugar concentration was obtained by pretreatment of WH is between 9.5 g/L and 20 g/L (Rezania et al., 2018). A group researchers determined that reducing sugar concentration obtained from WH varied from1.95 g/L to 12.84 g/L (Madian, et al., 2018). A group researchers reported reducing sugar concentration of 33.3 g/L from WH (Reales-Alfaro et al., 2013).

3.2.2 Bioethanol Yield and Quality

200 g sample of WH feedstock yielded 50 ml of bioethanol. The bioethanol was visibly free of suspended contaminants. The difference in percentage bio-ethanol yields (Table 1) could be attributed to the fact that acid hydrolysis yields more fermentable sugars, followed by enzyme hydrolysis and lastly alkali hydrolysis. However, these yields are much lower and this is attributed to the shorter period during saccharification and fermentation processes, and that less sugars were extracted during saccharification process leading to low production of reducing sugars and thus low ethanol yield. According to the USA standards for denatured ethanol, the minimum volume percentage of ethanol is 92.1 %. Some researchers in their study reported that ethanol yields of 97.50% sugar in

alkali treatment process which is higher than the acid treatment process 80.60% were achieved (Biswas et al., 2015). In a study by it was reported that ethanol yield was 0.22 g/g using acid hydrolysis, which was 76.3 % of the theoretical ethanol of the WH (Cheng et al., 2014).

3.2.3 pH

The pH of the Bioethanol was 4.5, 9.7 and 6.9 for acid, alkaline and enzyme hydrolysed pre-treatments respectively. This was attributed to the three treatments prior to recovery of the bioethanol during fractional distillation. The bioethanol from acid hydrolysis had the lowest value meaning is it very acidic, this could have been attributed by presence of the by-products like ethanoic acid contamination affecting the purity of the bioethanol. The bioethanol from alkali hydrolysis had a pH of 9.7 very alkali tending to 14 on the pH scale. This could be because of high purity brought about by the fast recovery during fractional distillation. The bioethanol from enzyme hydrolysis had a pH of 6.7 tending to neutral, this could have been because of the storage conditions of the bioethanol after fractional distillation.

3.2.4 Briquette Production

Cylindrical briquettes were produced from separate mixtures of water hyacinth and cassava, cow-dung and ant hill (binders) and their fuel properties determined. The briquetting process produced samples with a diameter of 4 cm and a thickness of 5 cm. The weights of the briquettes produced are presented in Table 2.

Table 2: The Briquette Energy Weights Using Various Binders

Binder used	Weight sample (g)
Cow dung	1.01
Ant-hill soil	1.07
Cassava starch	0.91
No binder	1.05

3.3 Energy Properties of Briquettes and Bioethanol Produced from Water Hyacinth

3.3.1 Bioethanol Quality

Table 3: Presents the Calorific Values of Bioethanol from Different Pre-Treatment Methods

Bio-Ethanol Quality Parameter	H1	H2	H3
Calorific value (MJ/kg)	26.3	26.4	26.7

Where: H1= acid hydrolysed, H2= alkali hydrolysed and H3= Enzyme hydrolysed.

Table 3 reveals slight differences in calorific values from the different pretreatment methods. This could have been attributed to storage of the bioethanol after distillation from all the three treatments. The Bioethanol could have been exposed to a damp place making it contaminated with water hence giving relatively low calorific values. Water combines with ethanol via intra-hydrogen bond thus reducing the bond energies of ethanol.

3.3.2 Calorific Value of Briquettes

A bomb calorimeter IKA C2000 model was used to determine the calorific value of the briquettes samples and the results are presented in Table 4.

Table 3: Calorific Values of Briquette Samples

Briquette with binder used	Cassava starch	Cow-dung	Ant-hill soil	No binder
Calorific value (MJ/kg)	8.061	9.034	2.076	7.174

Briquettes made with cow dung as binder had the highest calorific value followed by those with cassava starch; however, there was no significant difference between the calorific value of briquettes with no binder and those with cassava starch binder. The high calorific value of the cow dung briquette is attributed to the high fixed carbon in the dung and low ash content. Briquettes with Cassava starch as a binder had relatively high fixed carbon and relative ash content followed by water hyacinth alone because of its high fixed carbon content and low ash content with the least being anti-hill binder because of its extremely high ash content that makes the combustible time very low.

This is in comparison to what is reported in the calorific value of briquettes usually lies between 14-20MJ/kg (Munjeri et al., 2016). The calorific value for all the briquettes made in this study was less than 14 MJ/kg. This expressed the need to investigate methods of increasing the heating value of water hyacinth-based biofuels. When considering the calorific values of commonly used fuel species in Uganda, it ranges from 9.034 MJ/kg to 20.724 MJ/kg (Okello et al., 2013). Cow dung briquette had a significantly higher calorific value (9.034 MJ/kg) which is near to the higher value in the calorific value range of fuel woods such as *Eucalyptus grandis* used in Uganda. Anthill: Water hyacinth type briquettes had a significantly lower calorific value and this may be due to the partial burning that occurred during the production of this briquette type. Cow dung-water hyacinth briquettes had a significantly higher amount of calorific value (9.034 MJ/kg) than starch and anti-hill soil types.

3.3.3 Briquettes Quality

The briquettes quality was investigated by determining the proximate analysis using Thermo-gravimetric Analyser and results are presented in Figure 3.

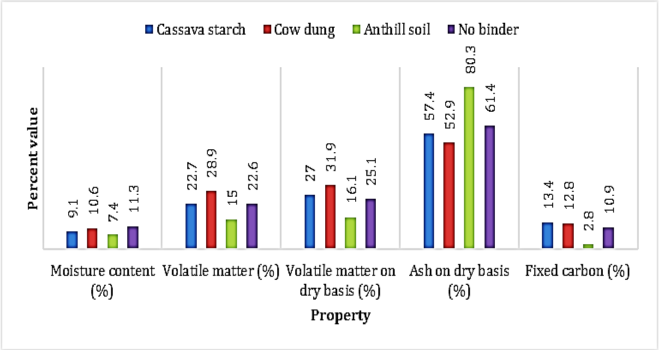

Figure 3: The quality of briquettes for the different binders and no binder

The briquettes made with cow dung binder (10.6%) and those with no binder had the highest moisture content (11.3%). Briquettes with cassava starch (9.1%) and anthill soil binder (7.4%) had moisture contents which are low. This implies that in terms of moisture content, briquettes with cow dung binder and those with no binder are most preferred. According to Huang, the recommended moisture content for briquettes lies between 10% and 18% (Huang, 2014).

3.3.4 Moisture Content

There is an inverse relation between the calorific value and the moisture content, that is, the lowest heating value was found in the briquette with the highest % moisture. This implies that a low moisture content reduces the calorific value and vice versa. And therefore, the high moisture content in water hyacinth feed stock makes bio-chemical conversion processes preferred to thermal chemical conversion processes. According to Masiello moisture content in briquette is considered as an impurity and could lower the heating value of the briquette (Masiello, 2004).

3.3.5 Volatile Matter

Cow dung and cassava starch bound briquettes had the highest and are therefore more preferred. According to Volatile Matter (VM) is the most flammable biomass component (Jack 2014). A low value of VM indicates that biomass is hard to burn or will affect its low reactivity, and vice versa. Meaning that the higher the VM, the more susceptible the biomass to burn and the higher its reactivity. Briquettes made with anthill soil binder had the lowest volatile matter and therefore are the least preferred.

3.3.6 Fixed Carbon

The results indicate that cassava-starch briquettes had the highest fixed carbon, followed by cow-dung, no binder and anthill soil briquettes. All the briquette samples had fixed carbon content below 15%. This value agrees well with the studies conducted by that ranged from 13.2 % - 16.8 %, with percentage fixed carbon of 15.97 % and with percentage fixed carbon of 10.0 % (Rezania et al., 2016; Carnaje et al., 2018; Bandara and Kowshayini, 2017). The higher the ash value, the lower the organic matter. The energy content of biomass correlates with the carbon content. Considering all the parameters used, that is, calorific value, moisture content, volatile matter, ash and fixed carbon; the cow dung briquettes are the most preferred followed by those with cassava starch binder and those briquettes with no binder.

4. CONCLUSION

The purpose of this study was to assess the potential of water hyacinth as an alternative to wood fuel through bioethanol and briquettes production. The study focused on bioethanol production basing on acid, alkali and enzyme pre-treatments to produce sugars, and fermentation of sugars into bioethanol. WH was also dried, pyrolysis carried out and pressed into briquettes using different binder types. The bioethanol produced from WH was of good quality and fit for use as a cooking fuel. Longer fermentation hours were likely to give higher quantities and quality of bio ethanol. The briquettes produced using cow dung and cassava starch binder had the best quality compared to those of anthill soil binder and no binder. Utilization of cow dung and cassava as a binders exhibit good binding characteristics. Therefore, the calorific values of cow-dung and cassava starch binder briquettes make them compete favorably with other biomass briquettes.

The high moisture content in water hyacinth make it preferred for biofuel made through biochemical conversion rather than thermal chemical conversion. However, if cheaper drying technics are identified, the thermal chemical conversion methods can be opted for. Drying water hyacinth near its place of harvest prior to transportation for biofuel production is also a feasible alternative. The lower ash content and higher organic carbon makes WH a significant biomass resource for production of bioethanol and briquettes. Bioethanol fuel of the WH had a higher calorific value as compared to the briquette fuel, but in terms of costs incurred, ease of production, technology requirement and time taken, briquettes are a preferred water hyacinth-based biofuel compared to bioethanol. However, there is need to identify the optimal water hyacinth-binder ratio for production of water hyacinth-based briquettes with a higher heating value as well as the most appropriate improved cooking stove for the water hyacinth-based briquettes.

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