

CHARACTERIZATION OF BIOCHAR PRODUCED FROM HERBACEOUS PLANTS AS ALTERNATIVE SOURCE FOR DOMESTIC COOKING

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ABSTRACT

Fuels are vital for energy generation, with fossil fuels posing environmental threats due to their emissions. Non-fossil fuels, such as those derived from biomass, offer sustainable alternatives. However, the depletion of wood fuel in regions like Nigeria necessitates exploring alternative sources like biochar. Depletion of wood fuel resources in Nigeria leads to reliance on costly alternatives like liquefied natural gas (LPG) and kerosene, with significant environmental impacts. This study aims to explore herbaceous biomass as a renewable alternative for domestic cooking, focusing on characterizing biochar. Herbaceous plants were collected, dried, ground, and carbonized. Biochemical, proximate, and ultimate analyses were conducted using ASTM standards to assess properties such as lignin, hemicellulose, extractives, moisture, ash, volatile matter, and elemental composition. Raw herbaceous plants (RHP) showed significant moisture reduction during preparation. Biochemical analysis revealed RHP's composition, with lignin content higher than literature values. Proximate analysis showed RHP's suitability for fuel use. Carbonization enhanced lignin content in carbonized herbaceous plants (CHP), making them more suitable for fuel utilization. Elemental analysis showed increased carbon content in CHP. Further studies should produce briquette samples from this feedstock and optimize relevant variables for the briquette-making process to enhance its efficiency and viability as a cooking fuel.

Keywords: Biochar, herbaceous plants, energy, domestic cooking

1 INTRODUCTION

Fuels are categorized into fossil and non-fossil types. When fossil fuels burn, they release harmful chemicals like carbon dioxide (CO₂), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO), posing significant threats to the atmosphere [1]. Non-fossil fuels, on the other hand, are considered environmentally friendly and sustainable, including those derived from forestry and agricultural waste. These fuels are cleaner and emit fewer greenhouse gases (GHG). Current estimates suggest that out of approximately 7.63 billion people worldwide, around three (3) billion rely on wood, kerosene, biomass, and coal for household cooking [2]. Consequently, there has been a notable increase in deforestation, resulting in an annual depletion of over 3% of the world's forested areas. Particularly in less technologically advanced nations, there is a growing daily demand for wood [3]. Nigeria, with a population exceeding 193.3 million and vast arable land, relies heavily on agriculture, particularly in rural areas [4]. Due to the dwindling supply of wood fuel for domestic cooking in Nigeria, liquefied natural gas (LPG) and kerosene have emerged as primary alternative fuels [5]. Residential cooking is the main source of energy consumption in Nigeria [6]. However, the depletion of wood and charcoal resources has led to increased

costs of alternative energy sources such as kerosene and LPG [7]. The environmental and ecological challenges associated with the extraction of these fuels are significant concerns due to their unsustainability and anticipated depletion [8]. Widespread use of fuelwood without adequate replenishment has detrimental effects on ecology in many nations, particularly with growing populations like Nigeria's, which demand energy for various purposes [8]. Herbaceous biomass has historically served as a fuel source but has gradually been replaced by fossil fuels since the availability and affordability of coal in the 1910s [9]. However, repurposing these abandoned waste materials holds promise as an alternative and eco-friendly energy source. One drawback of using raw biomass as solid fuel is its low energy density, limited fixed carbon content, high volatile matter (VM), and poor storage stability due to absorbed moisture, presenting challenges for direct utilization. Hence, converting these agricultural waste materials into biochar presents a viable solution. Biochar, a product of total pyrolysis, is fine-grained, porous substance rich in carbon, ash, Sulphur (S), nitrogen (N), hydrogen (H), and oxygen (O). Produced by heating biomass (such as agricultural waste, MSW, industrial waste) under oxygen-deficient conditions, biochar serves multiple purposes, including nutrient recycling, soil conditioning, income generation, waste management, and long-term carbon sequestration [10]. Recently, biochar has garnered attention for its various potential uses, including carbon sequestration, improving soil fertility and moisture retention, renewable fuel production, and scientific applications [11]. Therefore, there is a pressing need to explore alternative cooking fuel options that are renewable, environmentally friendly, locally available, and cost-effective. Biomass, as a renewable energy source, plays a crucial role in energy generation. Agricultural residues for instance herbaceous plants, are often left to decay on farmland, contributing to climate change, releasing greenhouse gases and polluting water. Therefore, one potential solution is to characterize this agricultural waste as an alternative source for domestic cooking. The aim of this work is to characterize biochar from herbaceous plants as an alternative source for domestic cooking and the objectives are to collect, dry, grind, sample and test the properties of the raw herbaceous plants (RHP) using biochemical, ultimate and proximate analysis and to carbonize the raw herbaceous plants (CHP) and test its properties using biochemical, ultimate and proximate analysis. Thus, this study underscores the potential of herbaceous biomass, converted into biochar, as a sustainable alternative for household cooking, offering environmental benefits and economic opportunities.

2 METHODOLOGY

Table 1 provides a comprehensive list of the materials utilized in the study, along with their respective functions, facilitating the process of characterizing biochar from herbaceous plants for alternative domestic cooking fuel and Table 2 outlines the apparatus and instruments employed in the study, each accompanied by its specification and designated function. These instruments were instrumental in conducting various analyses crucial for evaluating the properties of biochar derived from herbaceous plants for potential application as cooking fuel. The process involves feedstock selection, collation, and sampling. Next, the feedstock is burnt in a carbonizer, and then sieved to sizes (0.3mm, 0.4mm, 0.6mm and 1.7mm) based on the BS1377 [12] followed by characterization in the laboratory.

Table 1. Materials used in this study

| S/N | Materials | Function |
|-----|--------------------------|---|
| 1. | Herbaceous plants | Used as Feedstock in the briquette production |
| 2. | Mortar and pestle | Used for grinding the dried herbaceous plants |
| 3. | 500ml Measuring cylinder | To measure the amount of water |
| 4. | Sieve | Used to sieve the feedstock into different particle sizes |
| 5. | Flame lighter | Used to ignite the biochar briquette produced |
| 6. | Half sized drum | Used for as a carbonizer |
| 7. | Desiccator | Used to avoid the absorption of moisture |
| 8. | Crucible dish | To retain the substrates within the furnace |
| 9. | Holding Tong | Used for removing the hot crucible dish in the oven |
| 10. | Sample container | Used for packaging the samples (raw and carbonized) |

Table 2. Apparatus and instrument used in this study

| S/N | Instrument | Specification | Function |
|-----|--------------------------|--|--|
| 1. | Digital weighing machine | SR scales digital weight balance (SR300) | used for the weight determination of the samples |
| 2. | Hot air oven | Memmert 854 schwa Bach | Used to determine the moisture content of the sample |
| 3. | Griffin electric furnace | Gt Britain (1200°C) | To determine the ash content of the sample |
| 4. | Heating mantle | Mumbai - 400 016 | To determine the nitrogen content of the sample |

2.1 Collection, drying, sampling and testing the properties of the herbaceous plants

The feedstock for this study, Herbaceous plants (HP), was gathered from the University of Maiduguri, Borno State. Followed by cleaning and removal of dirt, sand, stones, and other unwanted things, the cleaned sample was allowed to dry in an open area before being ground and sieved into uniform sizes. The HP took was sun-dried for 14 days due to the rainy season, having lower temperature. The raw sample's biochemical, proximate and ultimate analysis was assessed using ASTM standards Plate 1 shows the herbaceous plant undergoing drying.



Plate 1. Drying of collected HP

2.2 Determination of Biochemical Composition

To analyze the biochemical composition of the feedstock (HP), the feedstock sample was uniformly ground to determine the contents of lignin, hemicellulose, extractives, and cellulose.

2.2.1 Lignin content

The raw herbaceous plants (RHP) were dried, and then 5g of the RHP (feedstock) material sample were weighed into glass boiling tubes and 3ml of 72% acid (H_2SO_4) was added to it. This process allows for the determination of the lignin concentration. To ensure complete hydrolysis, the mixture was left at room temperature for two (2) hours and then gently stirred for 30 minutes. After the first hydrolysis, 84mls of distilled water was added, and the second hydrolysis stage takes place in an autoclave at 121°C for 60 minutes. After allowing the resultant slurry to cool at room temperature, the hydrolysate was filtered using filtering crucibles. The next step involves assessing Acid-Insoluble Lignin (AIL) by drying the residues at 105°C and employing a Griffin electric furnace to incinerate the hydrolyzed samples at 575°C to eliminate ash content. Subsequently, the absorbance of the acid-hydrolyzed samples is measured at a wavelength of 320 nm using a UV-visible spectrophotometer to quantify the soluble lignin in acid. The total of acid soluble lignin (ASL) and acid insoluble lignin (AIL) yields the lignin content of the biomass sample was calculated using Equations 1 and 2 [13].

$$\%ASL = \frac{\text{Absorbance}}{\text{Molar absorptivity of soluble lignin}} \times 100 \quad (1)$$

$$\%ASL = (\text{Weight of dry hydrolysed residue after digestion} - \text{weight of ash}) \times 100 \quad (2)$$

2.2.2 Hemicellulose content

In order to ascertain the feedstock's hemicellulose content, 5g of dry feedstock was weighed and added to a 250 ml and 150 ml conical flask along with 0.5 ml of NaOH. Following 3.5 hours of boiling at

100°C, distilled water is added to the mixture to make up the volume. After cooling, the mixture is vacuum-filtered and then cleaned with distilled water (H₂O) to get a neutral pH. After that, the residue was dried in a hot air oven at 105°C until it reaches a constant weight. The dry feedstock's hemicellulose content (% w/w) was determined by comparing the sample weights before and after using equation 3 [13].

$$\% \text{hemicellulose} = \frac{\text{weight of dried biomass} - \text{weight of treated biomass}}{\text{weight of dried biomass}} \times 100 \quad (3)$$

2.2.3 Extractives content

To assess the extractives in the feedstock, the TAPPI T 264 cm 07 standard method, established by the pulp and paper industry and endorsed by ASTM, was utilized. This procedure, outlined in ASTM D1105-96, involves a 4-hour Soxhlet extraction using a combination of ethanol-toluene, followed by an additional 4-hour ethanol extraction, and subsequently, a 3-hour hot water extraction of the initially air-dried sample. The percentage weight of the extractives content is determined as the disparity in weight between the raw biomass and the extractive-free biomass, as indicated in Equation 4 [13].

$$\% \text{ Extractives} = \frac{\text{weight of extracted dried biomass} - \text{weight of treated biomass}}{\text{weight of extracted dried biomass}} \times 100 \quad (4)$$

2.2.4 Cellulose content

The cellulose content of the feedstock was determined using equation 3.5 as reported by [13].

$$\% \text{cellulose} = 100 - \% \text{lignin} - \% \text{hemicellulose} - \% \text{ash} - \% \text{extractives} \quad (5)$$

2.2.5 Determination of proximate Analysis

The Association of Official Analytical Chemists AOAC (1980) standard and the National Renewable Laboratory (NREL) standard techniques of analysis was applied in the proximate analysis of the RHP samples to determine the fixed carbon, volatile matter, ash content, moisture content, and total solid contents. The analysis uses the following procedure.

2.2.6 Moisture and Total Solid Content

The moisture content of the sample was determined by measuring the amount of moisture lost after drying at 105°C in a hot air oven. The loss at 105°C include other volatile materials in alongside water. Every sample was heated to certain temperatures under specified conditions, and the weight loss was used to calculate the moisture content of each sample the moisture content and total solids was calculated using Equations 6 and 7 [13].

$$\% \text{ Moisture} = 100 \frac{(\text{weight of dry crucible} + \text{dry sample}) - (\text{weight of dry crucible})}{\text{weight of sample received}} \times 100 \quad (6)$$

$$\% \text{ total solid} = \frac{(\text{weight of dry crucible} + \text{dry sample}) - (\text{weight of dry crucible})}{\text{weight of sample received}} \times 100 \quad (7)$$

2.2.7 Ash content

The process for determining the ash content complies to ASTM E1755-01 standard. The ash content was determined by using the amount of residues that remains after dry oxidation at temperatures between 550°C and 600°C. After being dried in the oven, each sample was weighed and put into a crucible with a specified weight. The sample was then ignited in a muffle furnace and burned for six hours at 600±25°C. After which the crucible was taken out and allowed to cool in a desiccator, the ash content was then calculated using Equations 8 and 9 [14].

$$\% \text{ash} = \frac{(\text{weight of crucible ash} - \text{weight of crucible})}{\text{ODW of samples}} \times 100 \quad (8)$$

Where ODW is oven dried weight of the RHP.

$$OWD = \frac{(Weight\ of\ air\ dry\ sample \times \% \ total\ solids)}{100} \quad (9)$$

The procedures outlined in ASTM D1762-88 was used in the assessment of the volatile matter (VM). For the sample's VM content, 1.0g was burned for one minute at 850°C in a Griffin electric furnace. The combusted sample's residual weight was then determined, and the sample's weight loss reveals the amount of volatile matter in each biomass sample. The sample's VM content was calculated using Equation 10 [14].

$$\% VM = \frac{(Oven\ dry\ weight\ of\ sample - weight\ of\ residue)}{oven\ dry\ weight\ of\ sample} \times 100 \quad (10)$$

2.2.8 Fixed Carbon

In order to determine the fixed carbon (FC) in accordance with ISO 1350 and ASTM 3172 standards, the crucible cover from the earlier volatile matter test was removed. Next, the crucible was heated over a Bunsen burner until the carbon has burned all the way through. Weighing the residue that remains after the initial measurement, the difference in weight indicates the fixed carbon. Equation 11 [14] was used to determine the fixed carbon content.

$$FC = 100\%VM - \%ash\ content \quad (11)$$

2.2.9 Determination of Ultimate Analysis

The ultimate analysis for the evaluation of the elemental composition of HP such as Carbon (C), Hydrogen (H), Nitrogen (N), Sulphur (S) and oxygen (O) in the sample. It was determined according ASTM D3176-09, 2009 standard, by using equation 12 [15].

$$Ultimate\ Analysis\ of\ coal = wt.\ \%(C + H + N + S + O) \quad (12)$$

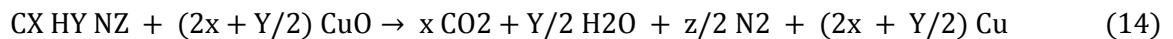
2.2.10 Carbon and Hydrogen Content

Carbon and hydrogen contents of the sample were determined using the combustion method. The samples were burned in an oxygen-rich atmosphere, and measurements were taken of the water vapour and carbon dioxide (CO₂) released during the process. The percentages of carbon and hydrogen were determined by comparing the results obtained before and after combustion. The reaction for the combustion process is illustrated in equation 13 [15].



2.2.11 Nitrogen content

The nitrogen content of the biomass samples was determined using the Dumas method. The sample was heated in the presence of cupric sulphate as catalyst, which causes the nitrogen to change into nitrogen gas (N₂). The releases (N₂) was observed with thermal conductivity, as shown in equation 14 [15].



2.2.12 Sulphur content

There are two methods available for determining the Sulphur content: combustion and non-combustion. The sample was heated up in an oxygen-rich environment, during the combustion process, which turns Sulphur into Sulphur oxide (SO₂), which is then collected and measured. The sample was analyzed with chemicals, in the non-combustible procedures turning Sulphur into sulphate ions (SO₄²⁻), and it was then being analyzed by spectrophotometry.

2.2.13 Oxygen Content

In coal analysis, we look at five main parts: carbon, hydrogen, oxygen, nitrogen, and sulfur, plus ash. But when we calculate how coal burns, we don't include ash. Instead, we focus on the total oxygen

content, which is crucial. To find this, we use the measured values of the main elements and ash. By using Equation 15, the difference makes it possible in the determination of oxygen.

$$\% \text{ Oxygen} = 100 - (\%C + \%H + \%N + \%S) \quad (15)$$

2.3 Carbonization of the herbaceous plant

The HP was cleaned and freed from all unwanted materials, they were then dried under the sun for 14days and carbonized thereby turning them into biochar, the biochar was then removed and dried off again of the moisture content. The HP underwent an open carbonization as shown in plate 2.



Plate 2. Open carbonization of the HP

3 RESULTS AND DISCUSSION

3.1 Properties of raw herbaceous plants (RHP)

3.1.1 Wet mass reduction

Figure 1 Illustrates the reduction in the moisture content of the herbaceous plant (HP) as it undergoes the preparation process. At various stages during the process, the weight of the HP was recorded. At the beginning, 15.8g of HP material was collected. After drying for 14days, the mass dropped to 8.0g and the weight further dropped to 4.23g after carbonization. The bulk was further lowered to 2.58g after sieving with 200 μ m sieve. As a result, during the whole preparation process, the HP lost the greatest amount of the bulk weight (about 84%) due to loss in moisture content.

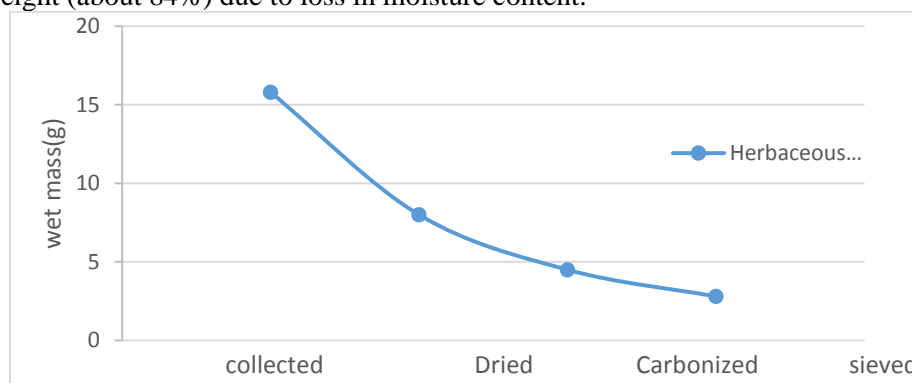


Figure 1. Loss in moisture content of HP during preparation process

3.1.2 Biochemical composition of RHP

The lignin, hemicellulose extractives, and cellulose content of the raw herbaceous plants (RHPs) were analyzed, and the results are detailed in Table 3. The RHP's lignin quantity obtained in this study was higher than what was previously reported by [16] as the lignin content for tension wood (17.85wt%) and lower compared to the compression wood's lignin content (39.78%), whereby the feedstock's cell walls structure decreases as the pyrolysis temperature rises. Also the lignin content in the RHP is higher than the one reported by [17] for different sources of herbaceous plants, for cane: bamboo (21-31%), sugarcane bagasse (19-24%), and straw: wheat straw (16-21%), rice straw (12-16%). The amount of lignin content

found in this research is close to the amount that was reported by [14] of lignin content of $36.93 \pm 2.89\%$. The hemicellulose of RHP as reported by [14] have $57.49 \pm 2.15\%$ of rice husk which is higher than the one reported in this study and lower in coffee husk ($20.62 \pm 2.02\%$) and groundnut husk ($23.35 \pm 2.05\%$). However, the hemicellulose of the RHP obtained in this research is higher than the one reported by [17] of cane (15-26%), sugarcane bagasse (27-32%), wheat straw (26-32%) and rice straw (23-28%). The RHP cellulose composition is lower than the one reported by John, (2020) for rice husk (20.81 ± 3.61), coffee husk ($40.45 \pm 1.58\%$), groundnut shell ($28.28 \pm 4.45\%$) and [17] for bamboo (26-43%), sugarcane bagasse (32-44%), wheat straw (29-35%) and rice straw (28-36%).

Table 3. Mean values of lignin, hemicellulose, extractives and cellulose for RHPs

| Sample | Biochemical Compositions(wt.%) | | | |
|--------|--------------------------------|-------------------|------------------|-------------------|
| | Lignin | Hemicellulose | Extractives | Cellulose |
| RHP | 36.20 ± 0.180 | 38.85 ± 0.075 | 2.35 ± 0.074 | 13.97 ± 0.490 |

3.1.3 Proximate analysis of RHP

All the proximate analysis results for RHP are presented in table 4. The total solid of RHP is lower than the one reported by [14] for groundnut shell ($87.51 \pm 0.70\%$), rice husk ($89.54 \pm 0.18\%$) and coffee husk ($87.69 \pm 0.51\%$). The volatile matter of RHP is lower than that reported by [14] for groundnut shell ($96.53 \pm 0.31\%$), rice husk ($76.51 \pm 0.88\%$) and coffee husk ($98.98 \pm 1.45\%$) [18] having (100%GS=74.26%) and (100%RH=69.74%). [19] reported that cotton waste leaf, soybeans waste and wheat straw have higher volatile matter content of 72.05%, 67.9%, 79.5%, 68.4% respectively compared to this present study of RHP having 58.148%, the ash content of the same waste having 3.1%, 5.2%, 4.7% and 7.9%, thereby suggesting their potential to be used in place of fossil fuels which shows that this feedstock can be used as a source of fuel. Ash content is a non-burning impurity that usually ranges from 5-40% [20] while the ash content of the RHP is closely in agreement with the one reported by [18] for rice husk (9.32%). The RHP for this study had moisture content ($21.107 \pm 0.280\%$) and ash content ($8.803 \pm 0.160\%$).

Table 4. Mean values of solids, moisture content, ash fixed carbon and volatile matter for RHP

| Sample | Proximate Analysis(wt.%) | | | | |
|--------|--------------------------|--------------------|-------------------|--------------------|--------------------|
| | T.S. | M.C. | A.C. | F.C. | V.M. |
| RHP | 78.900 ± 0.492 | 21.107 ± 0.280 | 8.803 ± 0.160 | 32.723 ± 1.633 | 58.147 ± 0.715 |

3.1.4 Ultimate analysis of RHP

Table 5 shows the elemental composition of RHP. Table 5 presents a comparison between the elemental composition observed in our study and the findings reported by [21]. This thorough examination sometimes referred to as the "ultimate analysis," makes it easier to determine how much air is needed for combustion and what makes up the combustion gases. The organic carbon content was estimated using the ASTM standard D1102-84 as a point of reference. A flame atomic absorption spectrophotometer was used to measure the hydrogen content in accordance with ASTM International's 2018 specifications. In the meantime, the suggested procedures were adhered to in order to determine the Sulphur and nitrogen content as reported by [22]. As shown from Table 5, the elemental composition of the RHP is closely in agreement with the one reported by [21], having carbon (51.2 ± 1.50), nitrogen (0.6 ± 0.008), sulphur (0.53 ± 0.22), hydrogen (5.3 ± 0.15) and oxygen (41.7 ± 0.40). The oxygen content in the RHP showed drastic reduction from $39.32 \pm 0.02\%$ to $16.92 \pm 0.38\%$ when carbonized. Nitrogen content in the RHP is also high having 0.72 ± 0.005 as compared to the one in literature.

Table 5. Mean values of carbon, hydrogen, nitrogen, Sulphur and oxygen for RHP

| RHP | Ultimate Analysis | | | | |
|---------------------|-------------------|------------------|-----------------|-----------------|------------------|
| | Carbon | Nitrogen | Sulphur | Hydrogen | Oxygen |
| Present study(wt.%) | 52.32 ± 0.572 | 0.72 ± 0.005 | 0.32 ± 0.02 | 7.35 ± 0.51 | 39.32 ± 0.02 |
| Literature (wt.%) | 51.2 ± 1.50 | 0.6 ± 0.08 | 0.53 ± 0.22 | 5.3 ± 0.15 | 41.7 ± 0.40 |

3.2 Properties of carbonized herbaceous plants (CHP)

3.2.1 Carbonization of CHP

Open carbonization was carried out for the HP. After carbonization, the initial weight of the HP underwent a massive reduction from 15.8g to 4.23g. Plates 3 and 4 shows the result for open carbonization of HP and preparation of the CHP for characterization respectively.



Plate 3. Result for open carbonization



Plate 4. Preparing CHP for characterization

3.2.2 Biochemical composition of CHP

The lignin, hemicellulose extractives, and cellulose content of the carbonized herbaceous plants (CHP) were analysed, and the results are detailed in Table 6.

Table 6. Mean values of lignin, hemicellulose, extractives and cellulose for CHPs

| Sample | Biochemical Compositions(wt.%) | | | |
|--------|--------------------------------|---------------|-------------|-------------|
| | Lignin | Hemicellulose | Extractives | Cellulose |
| CHP | 44.52±0.025 | 33.15±0.053 | 3.50±0.016 | 11.91±0.021 |

The carbonized herbaceous plants (CHP) has lignin content of about 44.52±0.025%. The extractives of the CHP is higher than the one of the RHP presented in table 3.1 but the amount of the extractives of RHP is closely in agreement with the one established by [14] for groundnutshell (2.24±0.35) but lower than that of rice husk(3.44±0.37) and higher than that of coffee husk (1.22±0.47). The composition of the cellulose CHP is 11.91±0.021%. The cellulose contents of CHP are lower than the one reported by [23] as 34.5-45.2% for Miscanthus, the author also reported the cellulose content of softwoods as 40-52% and that of hardwoods as 38-56%. From the result, the higher lignin content of CHP can be deduced that the briquettes will have a good combustion efficiency. A comparison for the two samples were analyzed and is shown in Figure 2.

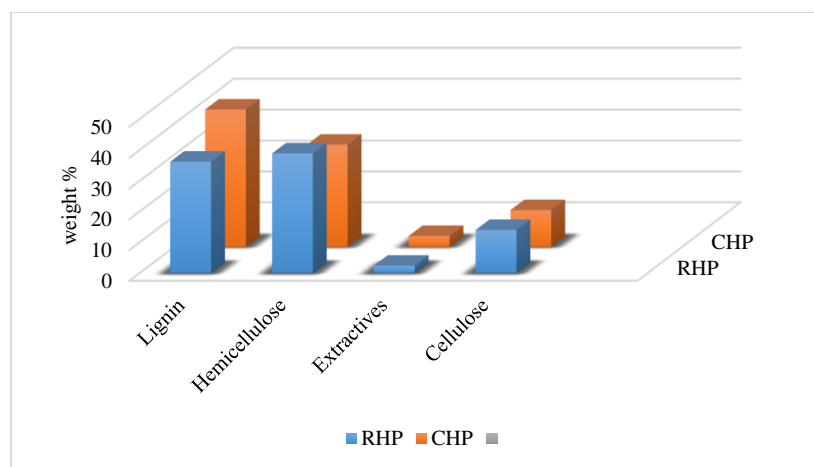


Figure 2. Comparison of biochemical analysis of CHP and RHP

3.2.3 Proximate analysis of CHP

All the proximate analysis results for CHP are presented in Table 7.

Table 7. Mean values of solids, moisture content, ash fixed carbon and volatile matter for the CHP

| Sample | Proximate Analysis(wt.%) | | | | |
|--------|--------------------------|-------------|-------------|-------------|--------------|
| | T.S. | M.C. | A.C. | F.C. | V.M. |
| CHP | 92.710±0.280 | 7.337±0.118 | 6.693±0.712 | 38.82±0.712 | 54.913±0.146 |

CHP had a total solid content of 92.710±0.16wt.% and consequently lower value of volatile matter content of 54.913±0.146wt.%. Also, the moisture, ash and volatile matter are all lower having 7.337±0.118wt.%, 6.693±0.712wt.% and 54.913±0.116wt.% respectively in the carbonized stage than the raw stage. The moisture content plays a crucial role in influencing both the ignition behaviour and the durability of a substance [18]. The amount of moisture and fixed carbon content determined in this study is significant enough to support briquetting and use as fuel because, [24] reported that higher moisture content lowers the chance of a biomass ignition. The moisture content of the CHP falls within the range of 7.50-8.00wt.% for some specific herbaceous plants as reported by [25]. The decrease in volatile matter is, to some extent, responsible for the reduced smoke emission when using carbonized briquettes. The ash content of the CHP having 6.693±0.712wt.% was the least between the two samples analyzed. [26] reported that the volatile matter for camellia oleifera decreased from 42.23-11.77wt.% as it undergoes carbonization.

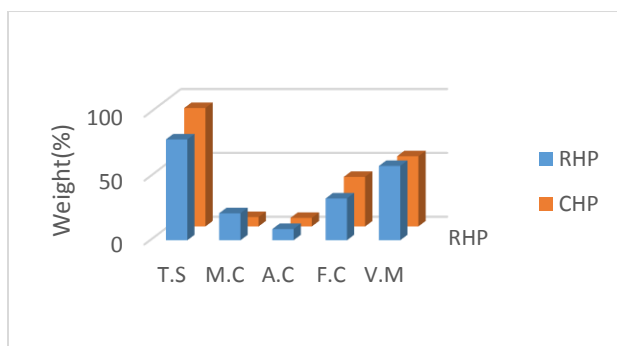


Figure 3. Comparison of proximate analysis of RHP and CHP

3.2.4 Ultimate analysis of CHP

Table 8 shows the elemental composition of CHP. These elements include carbon, hydrogen, nitrogen, Sulphur, and oxygen, among other chemical constituents. The results of CHP as compared to that of [27] from the table is higher than the one obtained from the present study. But the results for the elemental analysis of RHP and CHP of this study shows a significant increase in the CHP's carbon content, increasing from 52.32±0.572wt.% to 76.76±0.19wt.%. The nitrogen and Sulphur contents are low for both the samples indicating low ammonia (NH₃), other nitrogen-containing gases, hydrogen sulphide (H₂S) and other Sulphur containing gases. For the CHP, the low oxygen content of 16.92±0.38wt.% means less air will be required for the combustion of the briquettes. The hydrogen content was reduced from 7.35 ±0.51wt.% to 5.87±0.05wt.% as it was carbonized.

Table 8. Mean values of carbon, hydrogen, nitrogen, sulphur and oxygen for CHP

| CHP | Ultimate Analysis(wt.%) | | | | |
|---------------------|-------------------------|-----------|-----------|-----------|------------|
| | Carbon | Nitrogen | Sulphur | Hydrogen | Oxygen |
| Present study(wt.%) | 76.76±0.19 | 0.53±0.06 | 0.23±0.05 | 5.87±0.05 | 16.92±0.38 |
| Literature (wt.%) | 82.91 | 0.81 | 0.18 | 2.79 | 12.84 |

3 CONCLUSIONS

The research on the characterization of biochar produced from herbaceous plants (HP) as alternative source for domestic cooking has been carried and the following conclusions were made. The HP was collected, dried, grinded and sampled for further experimentation and the results were obtained. The results showed that the biochemical composition of the RHP is made up of 36.20% lignin, 38.85% hemicellulose, 2.35% extractives and 13.97% cellulose. Some of the compositions were similar to the values reported in the literature for herbaceous plants. The results also revealed that the RHP has higher moisture content, volatile matter, and ash content. It also contains 52.32% C, 0.72% N, 0.32% S, 7.35% H and 39.32% O. The HP undergoes an open carbonization process and the results obtained for the biochemical composition of the CHP comprises of 44.52% lignin, 33.15% hemicellulose, 3.50% extractives and 11.91% cellulose, it also revealed that the CHP has lower moisture content, volatile matter, and ash content with higher total solids and fixed carbon which indicates its suitability for fuel utilization. It also contains 76.76% C, 0.53% N, 0.23% S, 5.87% H and 16.92% O.

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