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Research Article

Combustion Characteristics of Briquette Fuel Produced from Biomass Residues and Binding Materials

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Proper management and effective conversion of biomass residues for biofuel production are crucial to reduce deforestation due to the cutting of trees for cooking and heating as a primary source of fuel and improving energy utilization of households. Thus, this study is aimed at investigating the effects of biomass residues of the coffee husk (CH), sawdust (SD), khat waste (KW), and dry grass (DG) and binding materials prepared from the waste paper pulp (PP) and clay soil (CS) under a low-pressure piston press densification machine. The biomass waste and binders were combined in a 3 : 1 ratio of CH : PP, CH : CS, SD : PP, SD : CS, KW : PP, KW : CS, DG : PP, and DG : CS. The briquettes were produced using a manually operated closed-end piston press machine compacted at an average pressure of 2 MPa. Briquette proximate and ultimate analysis of moisture content, volatile matter, fixed carbon, and ash content was determined using standard ASTM methods, while the calorific value was determined using a bomb calorimeter and data analysis was carried out using the R-program. Results revealed that the briquette produced from biomass residues has a mean value of fixed carbon and calorific value that ranged from 38.62 ± 1.53 to 41.75 ± 2.14 and 3979.21 ± 232.05 cal/g to 4577.34 ± 397.11 cal/g, respectively. Generally, briquettes produced from saw dust residue and the paper pulp binder had better quality of fuel and this could be used as an alternative source of energy and proper waste management option.

1. Introduction

Energy is very essential to human livelihood and makes significant contributions to economic, social, and environmental features of human development [1]. Nonrenewable energy sources such as fossil fuel, coal, and kerosene cannot be renewed and resulted in emissions of greenhouse gases (GHG), CO_2, SO_x, NO_x, etc. [2]. Renewable energy sources are so alternate and sustainable that are considered to be a preferable and better option than nonrenewable energy sources. Among the renewable energy sources, biomass fuels such as fuelwood, wood charcoal, agricultural residues, and animal dung are commonly utilized for household cooking purposes. However, the extensive and improper utilization of biomass fuel for household cooking resulted in deforestation [3], indoor air pollution [4], acute lower respiratory infections in women and children [5], and emission of greenhouse gases [6], which can be considered as a great challenge to the world, particularly in developing countries [7]. Biomass fuels consist of firewood, forest waste, animal dung, vegetable matter, and other agricultural residues that are highly utilized by many rural and urban households for domestic use [8]. In Ethiopia, more than 99% of the rural and 90% of urban households depend on biomass fuel for their domestic energy needs. In this country, fuelwood and charcoal are the primary sources of fuel for household cooking and heating [9].

Every year, 141,000 hectares of forest in Ethiopia is deforested to produce 3.2 million tons of charcoal [10]. Moreover, improper utilization of biomass energy sources results in flooding, global warming, soil erosion, climate change, and air pollution [11]. On the other hand, a huge amount of biomass waste was generated from agroprocessing industries, local markets, wood processing industries, and municipal areas. The improper management of these wastes causes air and water pollution and contaminates surface and groundwater supplies [12].

Improper deposition of coffee pulp from coffee processing areas causes pollution of water bodies and offensive odor, reduces the quality of domestic water use, and disturbs people who are living nearby the coffee processing areas in Gedeo Zone. Khat waste is also found everywhere such as on the roadsides, ditches, drainages, and open areas and on the street, which negatively affects the cleanness or aesthetic value of Dilla town. These khat wastes also serve as good breeding sites for pests and insects, clogging ditches and drainages. Moreover, inefficient utilization of the large production of sawdust and grass is observed in the study area [13]. Recycling biomass wastes into the production of briquettes helps to minimize environmental problems, particularly the accumulation of greenhouse gases [14]. Therefore, proper management of biomass waste in the production of briquette fuel provides a valuable addition to the sustainable and efficient utilization of biomass wastes [15].

Briquetting is a process of compressing loose biomass residues into a high-densified solid block that can be used as a fuel. Briquette from agricultural waste (biomass) contributes to the energy mix. The advantage of being able to transform biomass, which in its raw form has low density, low heating value, and high moisture content, to highly efficient fuel briquette is now of research interest [16]. The briquette fuels are advantageous to handle, have ease of transport, and improve heating value than other types of biomass fuel [17]. Briquetting improves the ultimate and proximate properties of biomass materials [18]. In addition, it provides a valuable addition to the sustainable and efficient utilization of the biomass residues [19]. Several investigators [20–24] have been reresearching on the potential, production, combustion properties, and quality of briquettes produced from different biomass wastes and binding materials with heavy-duty densified machines.

Numerous biomass residues are in abundant in Ethiopia, particularly in Gedeo Zone. However, there are no sufficient findings on the proximate and ultimate analysis of briquettes produced from coffee husk, sawdust, khat waste, and dry grass residues using paper pulp and clay soil binding materials under low-pressure hand pressing machines. Thus, properly utilizing and improving the quality of briquettes produced from an ample potential of selected biomass waste with low-pressure pressing machine and evaluating proximate and ultimate properties of briquettes are of paramount importance. In this sense, this study is mainly aimed at evaluating the effect of coffee husk, sawdust, khat waste, and dry Rhodes grass (*Chloris gayana*), residues with binding materials of paper pulp and clay soil on the proximate and ultimate analysis of briquette.

2. Materials and Method

2.1. Study Area Description. The study was conducted in Dilla University, Gedeo Zone, Southern Nations, Nationalities, and People's Regional State (SNNPRS), Ethiopia (Figure 1). Geographically, it is located at 6° 28′ 19″ N and 38° 17′ 10″ E with 1636 m elevation and 364 km distance from Addis Ababa. In Gedeo Zone, there are abundant wastes of coffee husk, khat, dry Rhodes grass, and sawdust. According to [13], household fuel usage is dependent on firewood, wood charcoal, animal dung, and agricultural residues, as well as unwise utilization of biomass wastes in the area is reported.

2.2. Material Collection and Preparation. Coffee husk (CH), khat waste (KW), sawdust (SD), and dry grass (DG) were collected from coffee processing industries, saw mill industries, local markets, and agricultural lands from the study areas. Sand, stone, and plastic materials were excluded, and the wastes were allowed to sun dry up to a low moisture content of 13% for CH, 11% for SD, 15% for KW, and 12% for DG which were recorded as described by the method of [25]. On the other hand, binding materials of waste paper and clay soil were collected from the offices and farms of Dilla University, respectively. Waste paper pulp was prepared by turning waste paper into small pieces and saturated in cold water for one day [26]. The paper to be used as a binder was then taken from the water and converted into a pulp using a pestle and mortar. The collected clay soil was carefully dug; impurities such as gravel and tree roots and other unwanted materials were removed, then hammer-milled until they could pass through a screen sieve of 1 mm size to be used as a binding material

2.3. Carbonization of Biomass Materials. Collected biomass wastes were carbonized to improve quality of producing briquettes. During the carbonization process, the dried biomass wastes were chopped into pieces of less than 1 cm. The prepared biomass wastes were carbonized using a conventional drum produced at Bako Agricultural Engineering Research Unit, Ethiopia. Each biomass waste was carbonized separately in an oxygen-scarce environment. Based on the method of [27], the carbonization efficiency was calculated using the following equation:

$$\text{Carbonization efficiency (\%)} = \frac{\text{weight of raw biomass waste}}{\text{weight of carbonized biomass waste}}. \quad (1)$$

Following carbonization, the biomass wastes were cooled to prevent the formation of ash, then ground with a pestle and mortar, and sieved using a 2 mm sieve. Finally, carbonized biomass wastes with a particle size of 2 mm were used for briquetting.

2.4. Preparation of Carbonized Biomass Waste-Binder Ratio and Briquetting. Using a manually closed-end piston press machine compacted at an average pressure of 2 MPa, various trials were carried out to determine the amount of binder necessary to bind each carbonized biomass waste. Finally, 3 (biomass waste) to 1 (binder) mixing ratio was selected [27] and a total of eight mixing ratios of samples (CH : PP, CH : CS, SD : PP, SD : CS, KW : PP, KW : CS, DG : PP, and DG : CS) with three replications were used for characterization.

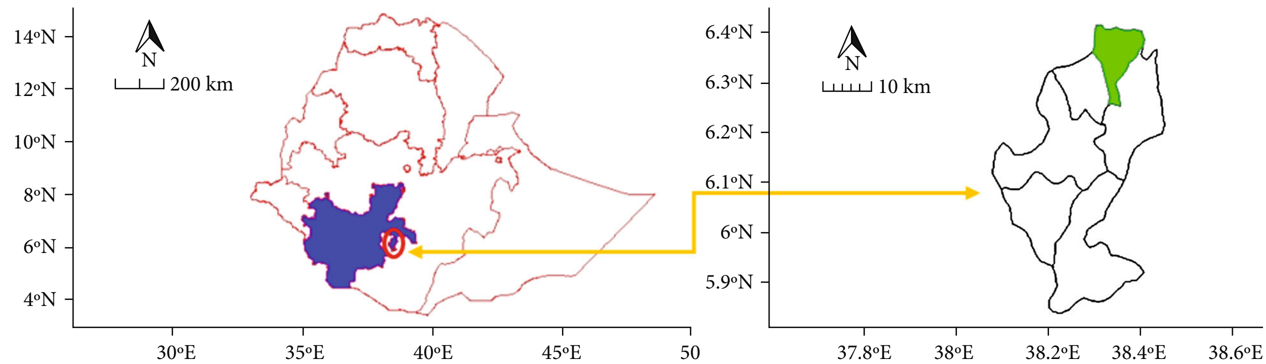

Figure 1: Research site location (blue color: SNNPRS; green color: Dilla Zuria woreda in Gedeo Zone).

2.5. Briquette Production Procedure. The briquettes were produced in a manually operated closed-end piston press with an inner diameter of 100 mm, a height of 50 mm, and a rod with a 20 mm outer diameter placed in the center of the briquette to create a hole. The hole helps to increase porosity and oxygen supply, thereby improving briquette combustion. A 500-gram mixed ratio of each prepared briquette was added in to closed-end piston press and compacted at an applied pressure of 2 MPa. The produced briquettes were placed on a flat surface and left to air dry for 30 days before determining the properties [28].

2.6. Briquette Characterization. Characterization was carried out to determine the percentage of moisture content, volatile matter, fixed carbon, ash content, and calorific value of the produced briquettes.

2.6.1. Moisture Content (wt %). The percentage moisture content was determined using the standard method of ASTM D2444-16 according to [29]. 3 g of each sample briquette was weighed out in a wash glass. The sample was placed in an oven dryer (DHG-9030A Model, Movel Scientific Instrument Co., Ltd, China) for 24 hours at 105 ± 3°C. This procedure was repeated until constant weight was obtained. The percentage of moisture content was calculated using the following equation:

$$\text{Moisture content } (\%) = \frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \times 100. \quad (2)$$

2.6.2. Volatile Matter (db %). The percentage of volatile matter (VM) was determined by heating the sample at 925 ± 20 °C for seven minutes in a Carbolite Gero (30-3000C AAF 11/3 model) ashing furnace based on the standard of ASTM D3175-18 [30]. The percentage of volatile matter was calculated using the following equation:

$$\text{Volatile matter } (\%) = \frac{\text{weight of oven-dried sample} - \text{weight of sample}}{\text{weight of oven-dried sample}} \times 100 \quad (3)$$

2.6.3. Ash Content (db %). The percentage ash content was determined using standard ASTM (D3174-12 method) [31]. The residual samples obtained after volatile matter determination (W1) were heated gradually in a Carbolite Gero (30-3000C AAF 11/3 model) muffle furnace at 700 ± 50°C and weighed after cooling to get the ash weight (W2). The percentage of ash content was determined using the following equation:

$$\text{Ash content } (\%) = \frac{\text{W1}}{\text{W2}} \times 100. \quad (4)$$

2.6.4. Fixed Carbon (db %). The percentage of fixed carbon was calculated by subtracting the sum of moisture content (MC), volatile matter (VM), and ash content (AC) from 100% using the following equation:

$$\text{Fixed carbon} = 100\% - (\text{MC} + \text{VM} + \text{AC}). \quad (5)$$

2.6.5. Calorific Value (cal/g). The calorific value of the briquette was determined using Parr 6200 and with bomb ID 39905 and M39889 bomb calorimeter [32]. One gram of the sample was palletized, placed in a sample holder (crucible), and then transferred to a steel capsule from the bomb calorimeter.

2.6.6. Sulfur Content (db %). Sulfur content was measured using the procedure of [33] adiabatic oxygen bomb calorimeter through calorimetric combustion of the briquette sample using the following equation:

$$\text{Sulfur content } (\%) = \frac{[\text{weight differenced} - \text{blank}] \times 13.73}{\text{weight of the briquette sample}} \times 100. \quad (6)$$

2.6.7. Determination of Ignition Time. The briquette samples were ignited at the edge of their bases with a Bunsen burner. The time taken for each briquette to catch fire was recorded as the ignition time using a stopwatch according to [34]. The ignition time was calculated using the following equation:

$$\text{Ignition time} = t_1 - t_0, \quad (7)$$

where t_1 is the briquette ignited time (sec) and t_0 is the burner lighted time (sec).

Table 1: Mean proximate and ultimate analysis of the sample briquettes.

Residues	MC Mean ± SD	VM (db) Mean ± SD	FC (db) Mean ± SD	AC (db) Mean ± SD	CV (cal/g) Mean ± SD	SC (db) Mean ± SD
Coffee pulp	7.22 ± 0.04^{a}	40.62 ± 1.58^{b}	40.03 ± 2.08^{a}	12.12 ± 3.21^{b}	4246.77 ± 255.76^{b}	0.04 ± 0.02^{b}
Sawdust	7.20 ± 0.07^{a}	42.44 ± 1.62^{a}	41.75 ± 2.14^{a}	8.62 ± 3.66^{c}	4577.34 ± 397.11^{a}	0.03 ± 0.01^{c}
Khat waste	7.24 ± 0.03^{a}	39.39 ± 1.94^{c}	38.62 ± 1.53^{b}	14.93 ± 2.90^{a}	3979.21 ± 232.05^{d}	0.05 ± 0.02^{a}
Dry grass	7.24 ± 0.03^{a}	40.13 ± 1.68^{b}	39.58 ± 1.52^{b}	12.72 ± 2.44^{b}	4167.92 ± 316.94^{c}	0.04 ± 0.02^{b}
p value	0.153^{ns}	0.042^{*}	0.012^{*}	0.002^{**}	0.005^{**}	0.032^{*}

Means within a column followed by the same letter are not significantly different at 5% LSD test.

2.7. Statistical Data Analysis. Data were tested to verify if the assumptions of analysis of variance (ANOVA) were met using Shapiro-Wilk's test in a completely randomized design. The significance level was set at $\alpha = 0.05$, and means were separated using Tukey's honestly significant difference test. The statistical analysis was performed using the R-program (version 4.1.2, 2021).

3. Results and Discussion

3.1. Proximate and Ultimate Analysis of Briquettes. Proximate analysis of producing briquettes indicates the percentage of the moisture content (liquid state), volatile matter (gaseous state), and fixed carbon (solid state); the percentage of inorganic waste material (ash); and calorific value for biomass energy user. The ultimate analysis indicates the chemical composition of the produced briquettes.

3.1.1. Moisture Content. The statistical analysis revealed that there was no significant difference in the moisture content values of briquettes ($p > 0.05$) among residues (Table 1). The mean moisture content values obtained in this study ranged from 7.20 ± 0.07 for sawdust and 7.24 ± 0.04 for khat waste and dry grass briquettes (Figure 2).

The briquettes made with sawdust residue exhibited a little lower moisture content compared to coffee husk, khat waste, and dry grass residues. The briquettes made with saw dust exhibited lower moisture content among other sample biomass briquettes. This might be due to relatively high lignin content, good porosity, being well dried, and high bulk density of sawdust residues as supported by [35] who reported that the higher lignin content, fineness of the oil palm trunk bark materials, and lower moisture content were observed than corn cob residue. On the other hand, the finding of [36] indicated that finely ground materials make very dense briquettes and the densification of fine materials releases excess water during compaction process. In this study, lower moisture content value was recorded compared with briquette produced from rice husk residue and cassava peel binder [37] and compared to the recommended tolerance level of moisture content (8-12%) of biomass briquettes reported by [38].

3.1.2. Volatile Matter. The ANOVA of the mean value of volatile matter of briquettes showed a significant difference ($p < 0.05$) among residues. The highest mean value of volatile matter of briquettes was found in sawdust (42.44 ± 1.62) while the lowest value was registered in khat waste (39.39 ± 1.94). The minimum volatile matter recorded in khat waste might be due to fine particle size, lower ignition time, and high bulk density of the briquette. In addition, [39] confirmed that biomass waste briquettes, which have low porosity and high bonding force, decrease volatile matter of briquettes and ignition time. The values of volatile matter obtained in this study are lower compared to the findings of [40] that recorded volatile matter of briquette produced from mixed sawdust of tropical hardwood species to range from 72.33% and 77.44%. In addition, [41] reported that briquettes produced from maize cobs have a volatile matter of between 57.82% and 62.91%. Volatile matter values of 68.7% and 70.77% were also shown from mango leaves and sawdust to produce briquette biofuel [42]. The discrepancies in the findings of this study with the previous researches could be due to the amount of volatile liquid other than water present in biomass wastes and binding materials. However, results of this study could be crucial for quality briquette production, which is supported by [43] who revealed that briquettes with the lower volatile matter have good quality parameters including easy ignition and burning smoothly.

3.1.3. Fixed Carbon Content. The analysis of variance indicated that there was a significance difference ($p < 0.05$) among biomass residues (Figure 3). Table 1 depicted that the highest fixed carbon content value was found in sawdust (41.75 ± 2.14%), followed by coffee husk (40.03 ± 2.08%), while the last value is recorded in khat waste (38.62 ± 1.53 %). The findings of this study are in agreement with [22] who found that the fixed carbon content of briquettes produced from coal dust and rice husk ranged from 27% to 61.76%. The fixed carbon of a fuel is the percentage of carbon available for combustion [44]. The highest percentage of fixed carbon content of sawdust briquette might be a good bondage and uniformity of particles size helpful to increase the fixed carbon content and heating value of producing briquette. Furthermore, this briquette generated a small amount of ash compared to other tested fuels of biomass wastes, which indicates that this fuel was highly reactive and has a high carbon conversion efficiency.

3.1.4. Ash Content. The statistical analysis of the ash content of briquettes produced from biomass wastes showed significant ($p < 0.05$) difference. The maximum (14.93 ± 2.90%) and minimum (8.62 ± 3.66%) values of ash content were

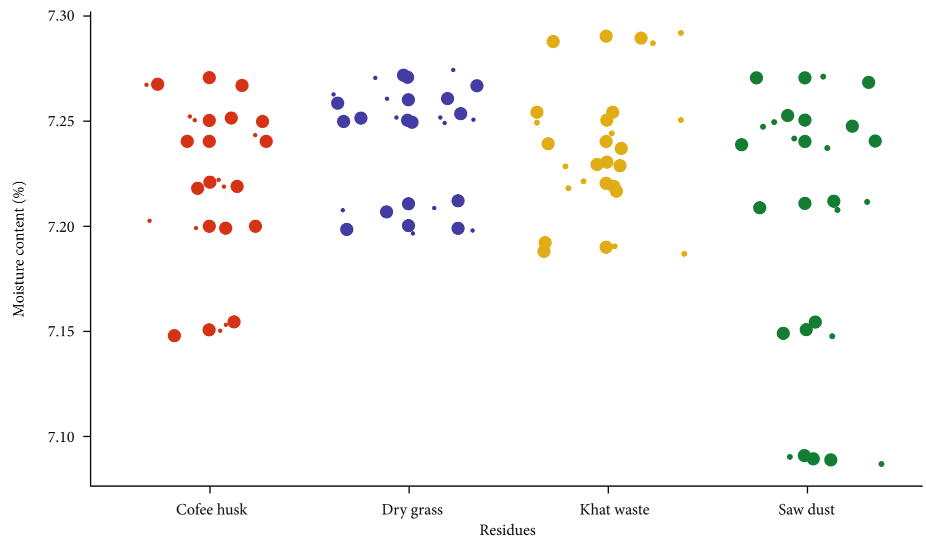

FIGURE 2: The effect of residues on percentage of produced briquette moisture content.

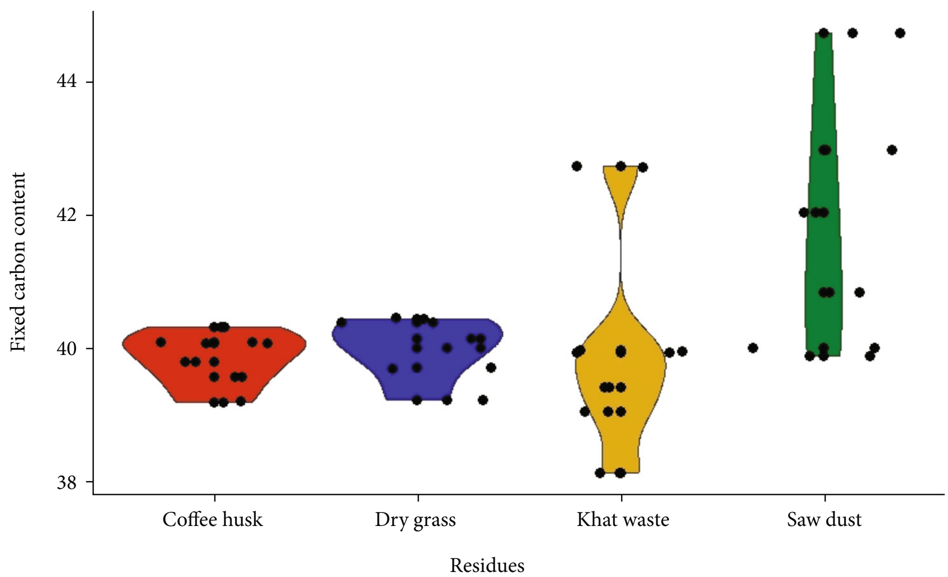

FIGURE 3: The effect of produced briquettes on fixed carbon percentage.

recorded in khat waste with binders and sawdust with binders, respectively (Figure 4). The results of ash content in this study are higher compared to the findings of [22] who suggested that the ash content for good-quality briquette should range from 3 to 4%. The result of this study is in agreement with that of [45] who opined that the difference in ash content of briquettes is due to variation in biomass wastes and way of briquette burning technique.

3.1.5. Calorific Value. The mean calorific value of briquettes produced from biomass wastes and binders is significantly varied ($p < 0.05$) among each other within all the organic amendments (Table 1). The highest calorific value was registered in sawdust with binders (4577.34 ± 397.11 cal/g) followed by coffee husk with binder (4246.77 ± 255.76 cal/g) while the lowest calorific value was recorded in khat waste with binders (3979.21 ± 232.05 cal/g) followed by dry grass (4167.92 ± 316.94) (Figure 5). The calorific values obtained from this study are higher than the findings of [45], who reported that the calorific value of sawdust and rice husk briquettes ranged from 1815 and 4516 cal/g. The highest calorific value of sawdust briquette might be the type of biomass waste, low moisture content, and highest fixed carbon present in the produced sample [2]. Therefore, the results of this study indicate that briquettes with this amount (4577.34 ± 397.11 cal/g) of calorific content could be used as an adequate alternative energy, reducing deforestation and environmental pollution.

This might be associated with a micro structural examination of the samples, as well as FTIR and XRD test. Interestingly, [46] indicated that cellulose, hemicellulose, and lignin content will give impact towards the capability of

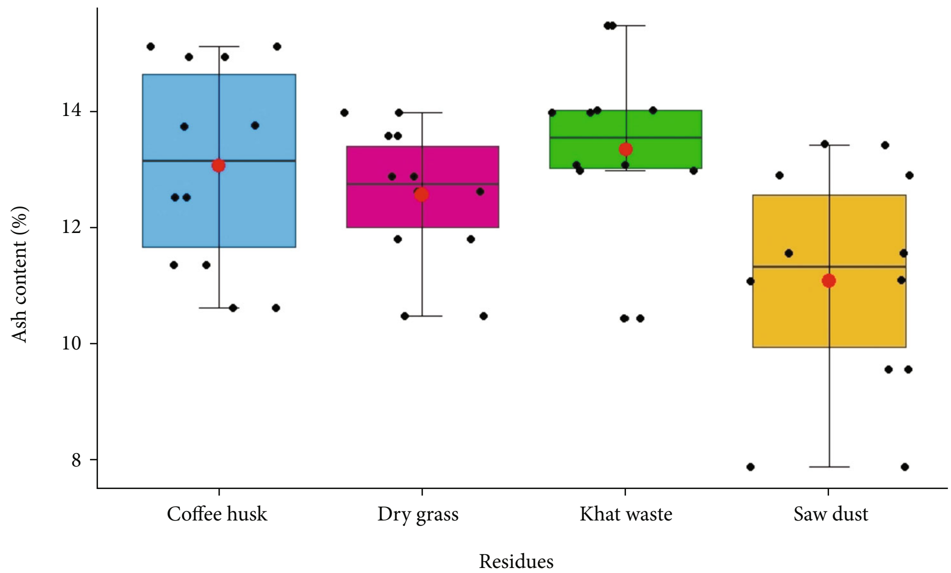

Figure 4: Response of ash content percentage to produced briquettes from different residues.

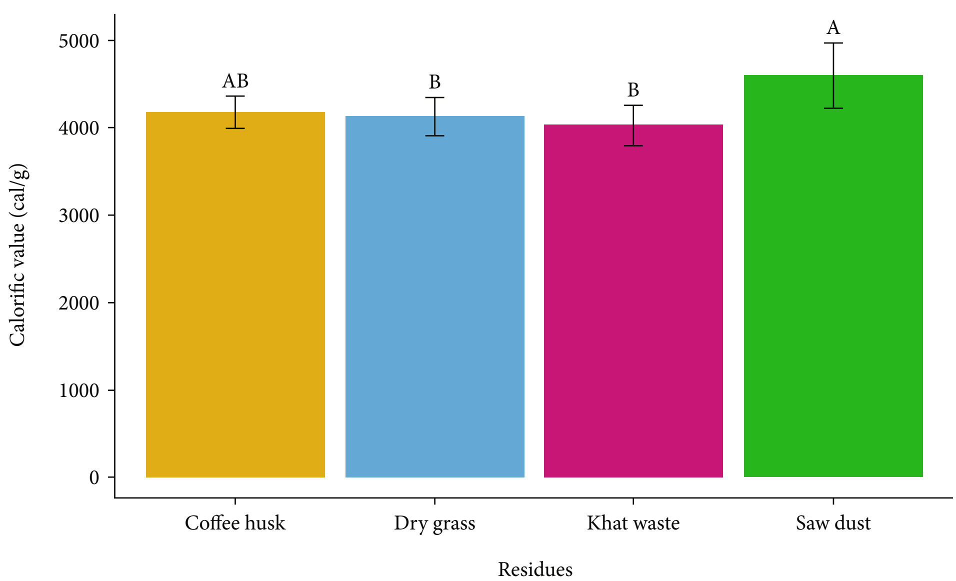

Figure 5: The effect of residues on produced briquettes' calorific value.

biomass to supply heat. Likewise, [47] determined that high lignin content of pineapple waste affects the heating value of biomass. According to [48], higher heating value was registered in oil palm bark compared to the corncob briquette due to high lignin content in oil palm bark briquette. Reference [49] concluded that biomass residues of lignocellulosic fuels increase with advancing of their lignin contents, which are responsible for the increase in fixed carbon content and heating value. The author further substantiated that the lignin content has an inverse relationship with the high moisture content and volatile matter.

3.1.6. Sulfur Content. The influence of biomass wastes of mean sulfur content showed a statistically significant difference ($p < 0.05$) (Figure 6). Sulfur content influences the combustion behaviors, levels, and types of emissions that will be generated during usage of the briquettes. The result of sulfur content of biomass waste briquette indicated that the least value of 0.03 ± 0.01% observed in sawdust briquette and the highest value of 0.05 ± 0.02% were recorded in khat waste briquette (Table 1). In this study, the sulfur content value recorded is lower than from corncobs and oil palm trunk bark briquettes with a waste paper binder in [35]. Based on the report of [50], low sulfur contents of sawdust briquette might cause minimal release of oxides which are harmful and environmental pollutants. The result of this study is similar to the reported values of sulfur content by [1] which was in the range of 0.02%-0.05% and [2] which was in the range of 0.02%-0.09% for the production and characterization of charcoal briquette making from different

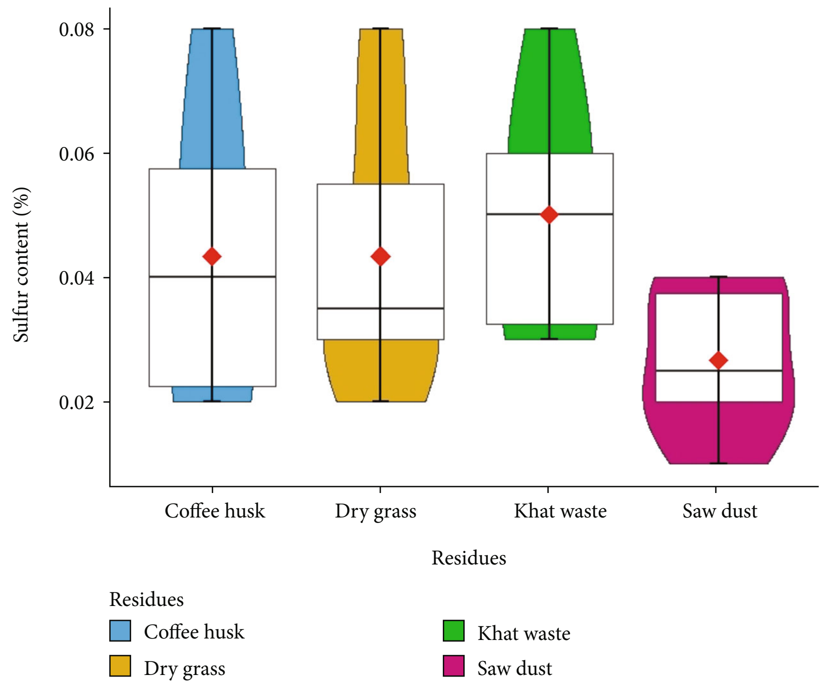

FIGURE 6: Effect of residues on percentage of sulfur content of the briquette.

TABLE 2: Mean ignition time of the biomass waste briquettes.

Residues	Ignition time (second) Mean ± SD
Coffee pulp	68.58 ± 7.26[b]
Saw dust	71.07 ± 8.24[a]
Khat waste	65.03 ± 7.12[c]
Dry grass	66.07 ± 6.86[c]
p value	0.031*
CV	4.24
LSD	0.89

biomass wastes. The report of [15] also indicated that briquettes made of residues which were less than 1% sulfur content are acceptable. Thus, briquettes made from experimental biomass waste could emit less amount of sulfur during combustion; as a result, it causes less air pollution.

3.2. Ignition Time (Second). The mean ignition time of briquettes produced from biomass wastes and binders was significantly varied ($p < 0.05$) (Table 2). The longest ignition time (71.07 ± 8.24 seconds) was observed in sawdust briquettes followed by coffee pulp briquettes (68.58 ± 7.26 seconds) whereas the shortest ignition time was scored in khat waste briquettes (65.03 ± 7.12 seconds). Generally, the ignition time of sawdust briquette is higher by 8.5% than the ignition time in khat waste briquette. The lowest ignition time of khat waste briquette might be accredited due to relatively low particle size, low porosity, and high bonding force of briquette [39].

3.3. The Influence of Binding Materials for Proximate and Ultimate Analysis of Briquettes. The statistical analysis revealed that paper pulp binding material is significantly different ($p < 0.05$) from the clay soil (Table 3). The result of volatile matter of briquette using paper pulp as a binder has the highest percentage of volatile matter of 42.06 ± 1.37% than clay soil binder (39.23 ± 1.38%). The higher volatile matter content of briquettes implies the higher the amount of emissions during burning. The study of [51] indicated that high volatile matter results in high combustibility at low ash content. This implies that low volatile matter is required for good-quality briquette. According to [52], incomplete combustion of clay soil leads to a significant amount of smoke and release of toxic gases. Reference [51] also indicated that low volatile matter briquettes might not be easy to ignite, but once ignited, they burn smoothly.

The addition of pulp paper as a binder increases fixed carbon content and calorific value of briquettes produced from selected residues. The percentage of fixed carbon briquettes with the addition of paper pulp binders was observed to be higher (41.50 ± 1.67%) than that of clay soil binder (38.49 ± 1.10%). The lower fixed carbon content of clay soil binder might be the presence of noncombustible material in a clay soil binding material. The higher fixed carbon content of paper pulp binder might also be contributing to significantly ($p < 0.05$) increase the calorific value of briquette (Table 3). The findings of [52] indicated that the lower calorific value of clay soil could be low fixed carbon and high ash content produced briquette.

The noncombustible element attained from biomass is ash. As illustrated in Table 3, the maximum ash content of 14.86 ± 2.11% was observed in composition soil binder briquette while the least ash content of 9.33 ± 2.71% for briquette produced from the paper pulp binder. The variability in the ash content of briquettes produced from

Table 3: Proximate and ultimate analysis of the sample briquette binding materials.

Residues	VM (db) Mean ± SD	FC (db) Mean ± SD	AC (db) Mean ± SD	CV (cal/g) Mean ± SD	SC (db) Mean ± SD
Paper pulp	42.06 ± 1.37^a	41.50 ± 1.67^a	9.33 ± 2.71^b	4406.97 ± 295.42^a	0.03 ± 0.01^b
Clay soil	39.23 ± 1.38^b	38.49 ± 1.10^b	14.86 ± 2.11^a	3965.33 ± 181.91^b	0.06 ± 0.02^a
p value	0.010^*	0.006^*	0.003^*	0.002^*	0.001^{**}

Means within a column followed by the same letter are not significantly different at 5% LSD test.

paper pulp and clay soil binders might be the noncombustible element found in the clay soil binder. The report of [53] indicated that ash content has a great effect on transfer of heat and oxygen dispersion to biomass fuel during combustion. The report of [52] also indicated that a noncombustible binder produces more ash content than using a combustible biomass binder. The ash content is an index of slugging property of the biomass.

The sulfur content of briquettes produced from selected binders affects its energy content. Briquette produced from using clay soil binder has higher sulfur content (0.06 ± 0.02 %) than paper pulp binder ($0.03 \pm 0.01\%$). The analysis of variance also indicated that there was significant ($p \leq 0.001$) higher sulfur content in clay soil-bound briquette than paper pulp-bound briquettes. However, briquettes produced in this study have lower sulfur content than briquettes produced from coffee husk which had a sulfur content of 0.16% [27] and rice husk which had 0.82% [52]. The lower sulfur content in the briquettes produced from addition of paper pulp binding material might have minimal potential to release sulfur, which would reduce indoor air pollution and the formation of acid rain [42].

4. Conclusions

This study demonstrated that briquettes produced from biomass residues and binding materials showed varied results in terms of proximate and ultimate analysis of briquettes. From this study, it could be concluded that briquette produced from sawdust residues had the highest fixed carbon content and calorific value among residues. Furthermore, sawdust residue had the lowest ash and sulfur contents. The results of the study also show that briquette produced from the paper pulp binding material has the highest calorific value. Therefore, the study shows that paper pulp is a better binding material than clay soil. From the observed results, it can be concluded that sawdust residue with binding material of paper pulp briquette was considered as high-quality and durable solid fuel briquettes. In general, the production of briquette from these residues and binding material helps to reduce the burden on forests and provide renewable, clean, and sustainable energy and a substitute for fuelwood and charcoal.

Data Availability

The data that support the findings of this study are available with the corresponding author and will be submitted upon request.

Conflicts of Interest

The authors declare there is no conflict of interest.

Acknowledgments

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