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Full Length Research Paper

# Preference choice of tree species for higher calorific value of charcoal: A case in semiarid region of Ethiopia

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**Abstract**

*This study was designed to determine charcoal consumers' preference of tree species and the calorific value of the charcoal produced in semi-arid region such as Goro District in South-East Ethiopia. A total of 134 households were selected proportionally using systematic sampling techniques. Samples were selected from five tree species such as Acacia nilotica, Acacia etbaica, Pappea capensis, Acacia seyal, and Acokanthera schimperi that processed into charcoal. The calorific value and fixed carbon of the charcoal specimens were computed through experimental determination of their moisture, volatile matter, and ash content, and analyzed using inferential statistics. The results shows that consumers are purchase charcoal made from Acacia nilotica, Acacia etbaica, Acacia seyal, Pappea capensis, and Acokanthera chimperi in a decreasing order of their preference. Laboratory analysis indicated the following result: moisture (4.220±0.84 – 9.8% ± 0.2), ash (3.2 ± 0.08 – 6.0 ± 0.05%), volatile matter (28.9 ± 0.66 – 32.56% ± 0.83), and fixed carbon content (51.6 ± 0.67– 63.7 ± 0.21%). The calorific value of Acacia nilotica, Acacia etbaica, Pappea capensis, Acacia seyal, and Acokanthera schimperi were found to be 31.5 ± 0.26, 30.6 ± 0.96, 29.9 ± 0.58, 29.6 ± 0.28, and 28.6 ± 0.05 KJ/g, respectively, and there is statistically significant difference (P-value<0.05). It is further concluded that except some variation community preference on tree species for charcoal production match with experimental results. In areas where fuel woods are available with proper management and afforestation, it is recommended to use high calorific value charcoal with modern stoves.*


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## 1. Introduction

Biomass fuels are in high demand for more than 2.5 billion people globally, particularly, for those dwelling near a forest and secured areas (Chakradhari & Patel, 2016; Gould et al*.,* 2018; Desta, & Ambaye, 2020). The utilization of biomass for cooking purposes has expanded drastically over the last few decades (Gould et al., 2018) and it is anticipated to reach 2.7 billion by 2030 (Rafaj et al., 2018). The high demand for this energy resource is dramatically rising due to low-level green electrification facilities in rural parts of the globe and unplanned urbanization initiated by rapid population growth (Gould et al*.,* 2018; Rafaj et al., 2018; Avtar et al., 2019; Li et al., 2016). Moreover, charcoal has been regarded as a noticeably affordable and dependable energy resource compared to electrical energy and fuel gasoline in low earnings households (Akowuah et al., 2012; Bisu et al., 2018). It has further gained an advantage over fuel wood due to its low cost of transportation, insufficient storage space, relative energy efficiency (Nabukalu & Gieré, 2019), less production of particulate matter and hydrocarbons (Akowuah et al., 2012), and fewer women workload and home health risk as compared to firewood (Sedano et al., 2016; Bouzarovski, & Petrova, 2015; Adesina et al., 2017; Hayas et al., 2019). However, its production is recognized as a cause of soil erosion and water depletion induced by deforestation and environmental degradation (Lal, 2012; Dibaba et al., 2020; Hanif 2018; Chiteculo et al., 2018).

In many African countries, charcoal production is regarded as one of the leading causes of forest degradation and deforestation. Traditional charcoal production procedures, which utilize wood of low calorific value, exacerbate the problem by necessitating the use of more wood to meet the same energy demands. Furthermore, the problem is exacerbated by unrestrained industrial charcoal production. On the other hand, considering the sustainable production potential of forests and with appropriate regulation of charcoal production, this industry can offer monetary contributions to the community. Like deforestation, massive greenhouse fuel emissions are also emitted, ranging from 7.2 to 9.0 kg $CO_2$ equivalent to a kilogram of produced charcoal (Bailis et al., 2004; Tengberg & Valencia, 2017). However, improved kiln technologies can increase carbonization performance, even lowering greenhouse fuel emissions. Major research efforts have focused on developing and modernizing cooking stoves in order to aid for the protection of forests and associated ecosystem services; however, they have largely overlooked the importance of prioritizing tree species for higher calorific value charcoal production in communities.

In areas where fire wood is accessible, charcoal producers have no incentive to enhance production. Improving charcoal production requires regulatory measures, systematic training on high calorific value species, and demonstration programs. Inefficient practices, conversion, and inappropriate end-use applied science for charcoal can have severe implications for the neighborhood and regional air quality. During charcoal manufacturing and burning, gases and particulate matter re emitted into working and living environments, leading to respiratory problems (Bailis et al., 2004). There are opportunities to reduce deforestation if the communities are using these high calorific value charcoals. For example, the time spent on cooking and heating is reduced by using these more efficient fuels, and the health impact associated is also minimized.

Communities can be benefited from tree with high calorific value charcoals. This, in turn, through afforestation and reforestation enterprises, communities can involve in new tree plantations to provide suitability of planted species to charcoal production. Further, by introducing these high calorific value charcoals coupled with innovative technical developments, it is possible to make charcoal a renewable and climate-friendly energy source for populations in rural and urban settings. Heavy reliance on charcoal making at the expense of tree species that produce high-quality charcoal which has socio-economic, health, and environmental implications. However, the driving force behind tree species selection for charcoal production is traditional and relies on indigenous knowledge, and experience. The tree selection of charcoal producers corresponds to their observation of the behavior of the value chain of charcoal production (Chiteculo et al., 2018). Some trees are selected because they are accessible others because they are easy for cutting, harvesting, carbonization, packing, and transport (Akowuah et al., 2012; Cardoso et al., 2015, Ndayambaje & Mohren, 2011). However, the identification of trees with high-quality fuel and charcoal has immediate economic, health, and environmental benefits (Nabukalu & Gieré 2019, Sola et al., 2019).

Furthermore, lack of proper knowledge, standards, and method for choosing desired tree species for this purpose is one of the fundamental constraints for conservation and administration of the present and future planting trees. Accelerated woodland clearance has far-reaching ramifications on the ecological service performing, and the wellbeing of the rural community and as such, it needs urgent intervention (Chiteculo et al., 2018; Acharya et al., 2018; Kiruki et al., 2018). Thus, understanding the consumers' preference of charcoal against their utilized charcoals' calorific value is crucial to suggest context-specific forest resource conservation-based strategies. When firewood transformed into charcoal, it obtained a more efficient fuel. Thus, preferences by community and energy characteristics of wood samples from charcoal samples are quite different. The preference of tree species for firewood and the energy properties of wood samples in the study location were determined by (Desta & Ambaye 2020). However, the preference selection of tree species by the community, the calorific value, and energy properties of charcoal samples are a research gap. Therefore, this research paper was designed to explore the preference of tree species for charcoal and the calorific value of the charcoal produced in the area, and test the hypothesis that whether there is significant mean difference in the CV among charcoal samples or not based on Duncan's multiple range test.

## 2. Materials and Methods

### 2.1. Description of the study area

The study area named as Goro district is situated 490 km southeast of Addis Ababa in Oromia Regional State in semiarid region of Ethiopia. It is located between $6^0$29”- $7^0$15” N and $40^0$10”- $40^0$45” E (Figure 1). It covers 1339 $km^2$ (133,900ha), with elevations ranging from 1200-2800 meters a.s.l. (Desta & Ambaye, 2020). A survey of the land in this woreda shows that 17.7% is arable, 38% is pasture or arid area and 39.3% of the semiarid area is forest or heavy vegetation covering 18.16 $km^2$, and the remaining 5.3% is a swampy, mountainous or otherwise unusable according to Socio-economic profile of the Bale Zone Government of Oromia Region (Desta & Ambaye, 2020).

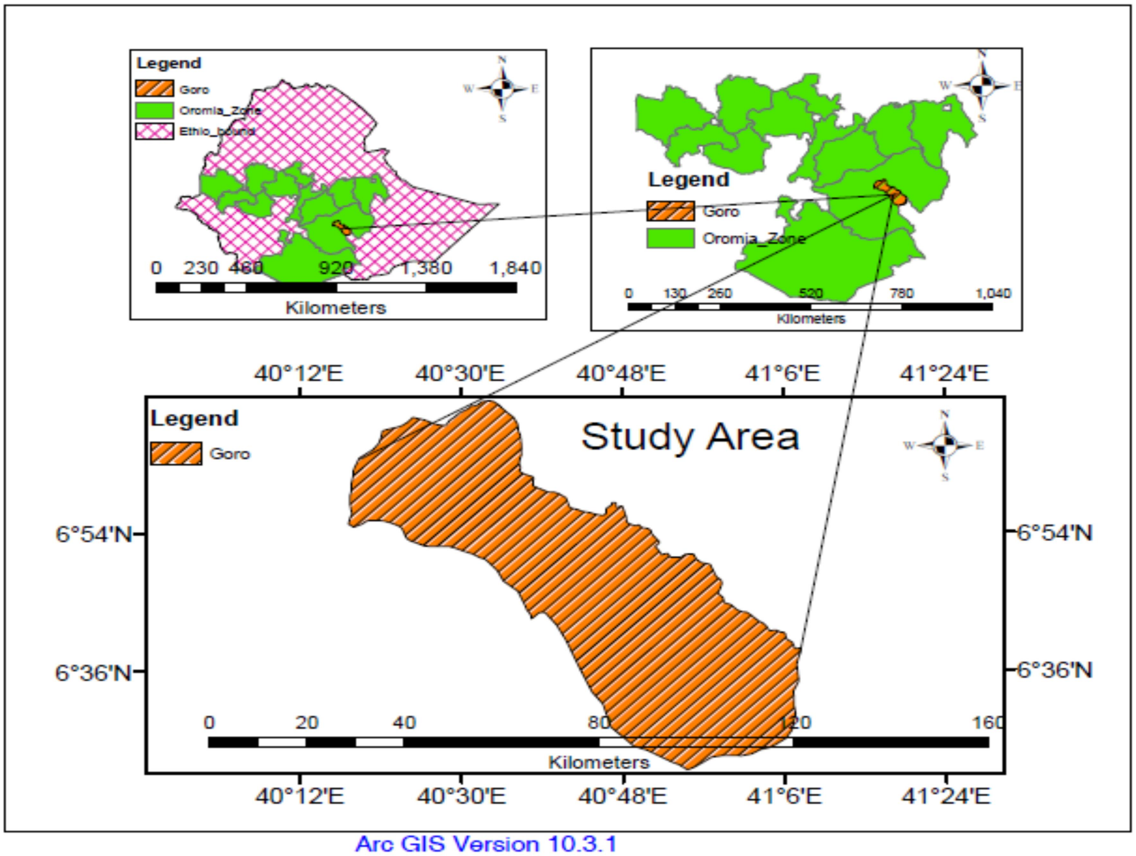


Figure 1: Map of the study area (Data Source: EthioGIS processed by the Authors)

**2.2. Data Collection Method**

Data on the tree species' identity used for charcoal production were collected using survey questionnaire and actual field observation. Samples collected were processed in the laboratory following standard method discussed under sub-section of experimental procedures. The materials used for sample collection included an electronic beam balance (accuracy: 0.0001g), GPS personal tracker, Nikon D5600 Digital Camera 18-55mm VR Kit, meter sticks, carving ax, and sample holder. Further, the samples were heated and dried using heating furnaces (Corbolite CWF 13000c, U.K) and a drying oven (Digit heat, J. P. Selecta, Germany). A grind wood crushing machine (SL: 1-100) was used to prepare the charcoal specimens for laboratory analysis.

**2.3. Methods**

***2.3.1. Study Design***

Cross-sectional household survey and field observation were employed to characterize tree species and extract the samples for laboratory evaluation. The interview was conducted on selected key informants (charcoal producers). The instrument for the cross-sectional household survey was a semi-structured questionnaire.

***2.3.2. Household Sampling Techniques***

***Sample Size***

The sample size was determined using the following formula (Dibaba et al., 2020).

$$no = \frac{z^2 pq}{d^2} \rightarrow n = \frac{no}{1 + \frac{no \_ 1}{N}}$$

Where

$no =$ The desired sample size when the population is greater than 10,000

$n =$ Number of sample size when population is less than 10,000

$z =$ 95% confidence limit i.e. 1.96

$p =$ 0.1 i.e. (proportion of the population to be included in the sample) i.e. 10%

$q =$ 1-0.1 i.e. (0.9)

$N =$ Total number of population

$d =$ Margin of error or degree of accuracy desired (0.05). 5% contingency is considered for households who may refuse to participate in the questionnaire. The number of total households in the two kebeles was 2048. Thus using the above equation the sample size for households was 134.

The study area was selected purposely due to forest cover and charcoal production, and the multistage sampling procedure was utilized. This was followed by selecting two *kebeles,* namely Gadulla and Bale Anole, from five Kebeles using a simple random sampling method. The number of households in Bale Anole and Gadulla were 1482 and 565 respectively. From the total of 2048 households (Desta & Ambaye, 2020), 134 population samples were proportionally selected by a systematic random sampling method. The five species were preferred by consumers as determined by their tally frequency marks. Furthermore, to identify the seven tree species for charcoal making, ten key informants, five individuals from each kebele were selected by snow ball sampling technique. Since key informants are individuals whom are knowledgeable about tree species.

***2.3.3. Wood fuel samples collection techniques***

Thirty 20x20m sub-plots were randomly established in the fifteen hectares of customary woodlands. Using a simple random sampling technique, three trees from each species were selected, and by June 2019, all preferable tree species in all subplots were counted and registered. The trunks of selected preferable tree species whose diameters ranging from 5cm to 10cm and their height varying from 10 cm to 15 cm were prepared. Trunks from matured trees estimated between ten to twenty years of age were used for extracting fifteen charcoal specimens. Since, charcoals from matured trees have high calorific value than young trees. After leveling each sample, it was stored in the plastic bag until the first measurement was taken. All samples were weighed two hours after cutting using a measuring balance after removing the bark.

***2.3.4. Preparation of Charcoal Samples***

The collected tree samples were sun-dried for eight weeks to analyze ash content, volatile matter, and moisture content. Fixed carbon and calorific values were calculated by equations (4) and (5), respectively. A disk of 10 cm height was taken from the trunk of each tree. Each disk was sawn into strips of 3.0 cm width. From the strips, cubes of 3 x 3 x 3 cm samples were made. Fifteen specimens were prepared for wood charcoal. The strips were oven-dried before analysis.

*2.3.5. Carbonization process*

Fifteen specimens, three from each species prepared as stated above for charcoal production, were oven-dried at 103 ± 2°c. They were also carbonized through an electric tube furnace model (Corbolite CWF1300$^0$c, U.K). The carbonization process was conducted under an inert atmosphere (nitrogen flow gas at the rate of 300 ml min$^{-1}$) and at 450$^0$C maximum final temperature. The specimens were further grounded with the grind wood crushing machine to attain charcoal particles with a 1-2mm diameter.

*2.3.6. Experimental Procedures*

Moisture content, volatile matter and ash content were determined using the proximate chemical analysis of wood charcoal while fixed carbon and calorific value were calculated from the given equation. The following designations were used for the determination of percentage of moisture content, percentage of volatile matter, and percentage of ash content. **A** = Air-dried weight of charcoal (g), **B** = weight of the oven-dried charcoal after 14 hours (g), **C** = weight of the sample after 10 mins in the furnace at 550˚C (g) and **D** = weight of ash (g). The charcoal specimen used for moisture content was also used for volatile matter and ash content determination.

*2.3.6.1. PMC*

A standard protocol was followed placing approximately 5 g of each charcoal specimen in a porcelain crucible (Akowuah et al., 2012). Each sample was dried to constant weight in an oven at a temperature of 103 ± 2°c for 14 hours. The loss in weight was taken as moisture. The moisture content was calculated (Desta, & Ambaye 2020; Aller et al., 2017; Álvarez-Álvarez et al., 2018) using the following equation:

$$PMC = \left( \frac{A - B}{B} \times 100 \right) \quad (1)$$

*2.3.6.2. PVM*

The percentage of the charcoal specimens' volatile matter was determined following ASTM International (2008) ASTM D3175-11 (Desta & Ambaye, 2020; Okello et al., 2001; Mitchual et al., 2014). The oven-dried charcoal specimen was kept in a furnace at a temperature of 550˚C for 10 min and weighed after cooling in a desiccator. The volatile percentage matter was estimated by (Desta & Ambaye 2020; Akowuah et al., 201; Aller et al., 2017; Álvarez-Álvarez et al., 2018).

$$PVM = \left( \frac{B - C}{B} \right) \times 100 \quad (2)$$

*2.3.6.3. PAC*

The percentage of ash content of the charcoal specimen was determined per ASTM International (2008) ASTM D 1102-8 (Desta & Ambaye 2020; Okello et al., 200; Mitchual et al., 2014). This was done by heating the oven-dried mass of each charcoal sample with an electric furnace at a temperature of 600˚C for four hours. After cooling, the sample was weighted to represent the ash residue. The ash content was determined by (Desta & Ambaye 2020; Akowuah et al., 2012; Aller et al., 2017; Álvarez-Álvarez et al., 2018).

$$PAC = \frac{D}{B} \times 100 \quad (3)$$

*2.3.6.4. PFC*

The PFC (Akowuah et al., 2012; Aller et al., 2017; Álvarez-Álvarez et al., 2018) as calculated using the equation (4) as follows:

$$PFC = 100 - (PVM + PMC + PAC) \quad (4)$$

#### *2.3.6.5. CV*

The CV (Akowuah et al., 2012; Aller et al., 2017; Álvarez-Álvarez et al., 2018) of the sample was calculated by the equation (5):

$$CV = 2.326(147.6C + 144V) \quad (5)$$

Where

C = the percentage of fixed carbon determined in the equation (4)

V= the percentage of a volatile matter determined in the equation (2)

#### *2.3.7. Data Analysis*

Statistical Analysis System (SAS) version 9.0 was used at a confidence level of 95%. Duncan's multiple range tests at a 0.05 level of probability was applied to determine the statistical difference in the mean of calorific value among charcoal samples'. Correlation analysis was carried out for each energy properties of the charcoal samples with their CV.

## 3. Results and Discussions

### 3.1. Preferred tree Species

**Table 1:** The tree species most preferred by study population, the extent of preference, mean diameter, and the total number of each species in the study area.

| Species scientific name | Local name (Oromo) | Frequency of preference | Mean Diameter (cm) | Total No of each species |
|---|---|---|---|---|
| 1. *Acacia nilotica* | *Burquqqee* | 98 | 5.8 | 67 |
| 2. *Acacia etbaica* | *Doddottii* | 82 | 5.7 | 86 |
| 3. *Acacia seyal* | Waaccuu | 71 | 5.9 | 63 |
| 4. *Pappea capensis* | *Biqqaa* | 63 | 6.6 | 55 |
| 5. *Acokanthera schimperi* | *Qaraaruu* | 40 | 5.4 | 74 |

Source: Own Survey, 2019

The study populations in the area have time-tested indigenous knowledge about their way of life and their environment in general. Their skill and knowledge about the best tree species to utilize for charcoal making is part of their indigenous experience. Data analysis from key informants and survey participants shows that *Acacia nilotica, Acacia etbaica, Acacia seyal, Pappea capensis, and Acokanthera schimperi* trees were the most preferred species in their order of preference. Participants explained that duration of burning/ permanency, amount of heat produced, amount of smoke produced during burning, ignition capability, and amount of ash after production were critical to judge charcoal quality. Furthermore, the quality of charcoal was evaluated by proximity, relative softness and fragility, ease of handling, and market value. For instance, good charcoal is described as one that burns for a long time, creates high heat, emits little smoke, and produces a tiny quantity of ash when burned. The fuel characteristics preferred by the study communities were similar to other study reports (Cardoso et al., 2015; Kituyi et al., 2001; Tabuti et al., 2003). The charcoal makers' criteria for charcoal quality in the study area were detailed and consistent with the scientific observations. Key informants stated that charcoal demand has increased while access to preferred tree species has declined remarkably.

**Table 2**. Mean values of energy properties of charcoal specimens

| Species name | PMC | PAC | PVM | PFC | CV(KJ/g) |
|---|---|---|---|---|---|
| | Mean±stdv | Mean±stdv | Mean±stdv | Mean±stdv | Mean±stdv |
| *A.nilotica* | $4.220^{B}\pm0.84$ | $3.180^{E}\pm0.08$ | $28.875^{B}\pm0.66$ | $63.725^{A}\pm0.21$ | $31.549^{A}\pm0.26$ |
| *A. etbaica* | $5.987^{BA}\pm3.18$ | $4.082^{D}\pm0.07$ | $29.468^{B}\pm1.42$ | $60.464^{B}\pm2.15$ | $30.628^{BA}\pm0.96$ |
| *P. capensis* | $7.000^{BA}\pm1.77$ | $5.008^{C}\pm0.26$ | $30.156^{B}\pm0.71$ | $57.837^{CB}\pm2.15$ | $29.957^{BC}\pm0.58$ |
| *A. seyal* | $7.307^{BA}\pm0.80$ | $5.711^{B}\pm0.02$ | $30.801^{BA}\pm0.31$ | $56.182^{CD}\pm0.51$ | $29.605^{BC}\pm0.28$ |
| *A.schimperi* | $9.773^{A}\pm0.20$ | $6.031^{A}\pm0.05$ | $32.585^{A}\pm0.83$ | $51.611^{D}\pm0.67$ | $28.633^{C}\pm0.05$ |

According to Duncan's multiple range test values labeled by the same superscript letters in each column are not significantly different at α=0.05. F calculated for **CV=**20.670 and for fixed carbon=20.670.

The hypothesis stating that there is significant mean difference in the CV among charcoal samples was tested by Duncan's multiple range test. The result showed that there is significant mean difference in the CV among charcoal samples. CV of each species were significantly different except *P. capensis and A.seyal* at α=0.05. There exist variations in CV of species under study.

### 3.2. Calorific Value

Calorific value (CV) is a standard measure of the energy content to characterize fuel property (Akowuah et al., 2018). Table 2 discusses the principal component analysis (PCA) of the calorific value of charcoal determined in five tree species from the study area. The lowest CV (28.633KJ/g ± 0.05) as recorded for *Acokanthera schimperi* while the highest (31.549KJ/g ± 0.26) was observed in *Acacia nilotica.* Since the calculated F value is nearly equal to 20.670, which is greater than the critical value 3.478, showed that, the CV value of the species under study is significantly different at α=0.05 among the five charcoal samples. Furthermore, CV is determined primarily by the difference in chemical contents of charcoal which is influenced by genetic and environmental conditions (Liu, 2019). The study revealed that charcoal samples with higher heating values have lower moisture content, ash content, and volatile matter. The observed high CV for *A.nilotica* species was due to low ash content and fixed carbon content in the charcoal of this species (Ajimotokan et al., 2019). Similar findings which indicate the direct relationship of CV with fixed carbon content were also reported by Stanturf et al. (2013).

The communities' charcoal choice was compared to the calorific values. Their preference was corroborated by the calorific values, except for the *A.seyal* and *P.capensis* species. These inconsistent choices may be attributed to other criteria such as availability, proximity, market value, and flammability of the wood. Overall, the communities considered the calorific values of the charcoal when choosing what type of wood to use. Similar results were obtained by other studies (Cardoso et al., 2015; Ndayambaje & Mohren, 2011). According to Aref et al. (2003) and Oyedun et al. (2012), the average calorific values of *Acacia seyal* was 6590 cal/g (27.57 KJ/g) which is closer to finding as indicated in Table 2. Research reports indicate that CV varies by the age of the trees. The matured trees about 20 years old are thought to have a higher calorific value than those between 2 to 6 years (Kumar et al., 2010). In the current study, *A.schimperi* had the highest PMC, PAC, and PVM but the least PFC and CV as indicated in Table 2. The CV further depends on the PVM and the carbonization temperature (Akowuah et al., 2012).

### 3.3. The Moisture Content

One of the main parameters that regulate the quality of charcoal is the moisture content. Low moisture content implies a higher calorific value (Akowuah et al., 2012). According to Akowuah et al. (2012), moisture content affects the burning characteristics of biomass material. As indicated in Table 2, *A. nilotica (*31.549 KJ/g ± 0.26) contains the highest calorific value and less moisture content (4.220% ± 0.84). Unlike *A. nilotica, A. schimperi* has the highest moisture content (9.773% ± 0.20) and the lowest calorific value (28.633 KJ/g ± 0.05). Therefore, there is an inverse relationship between calorific value and moisture content (see Table 2). The present finding is consistent with previous studies (Rafaj et al., 2018; Aref et al., 2003) which noted that the lower the moisture content the higher the calorific value. The value of moisture content of *A. seyal* in the current study was 7.307% which is higher than the previously study finding by Aref et al. (2003). This variation in the results might be due to mineral content of soil, the sample preparation and analysis (Liu, 2019).

### 3.4. Ash content

The ash content percentage was calculated by comparing the dried weight of the ash residue in the furnace to that of the oven-dried weight of the charcoal specimen. Charcoal with the highest calorific value has the least ash content (Stanturf et al., 2013). The ash contents of the charcoal produced from five preferred tree species are presented in Table.2. The ash content was varying from 3.180% ± 0.08 (*Acacia nilotica*) to 6.031% ± 0.05(*Acokanthera schimperi*). Charcoals produced from various species showed a significant difference (α=0.05) in their ash content. The ash content of charcoal in other studies ranged from 0.5% to more than 5% depending on the species of the wood (Stanturf et al., 2013). There is an inverse relationship between the percentage of ash content and the calorific value. Similar studies also show that a high heating value can produce low ash content (Stanturf et al., 2013). While *Acacia nilotica* has the highest calorific value with the lowest ash content, *Acokanthera schimperi* has the least calorific value with the highest ash content. As Koppejan et al. (2012) noted, the highest ash content of *Acokanthera schimperi* is indicator of high mineral content inside. The value of the ash content of *Acacia nilotica* obtained in the present study is 3.18% and that is inconsistent with the ash content found by other researchers (Kumar et al., 2009), which was 2.8%. Moreover, Aref et al. (2003) also reports that the average ash content of *Acacia seyal* was 7.02%. The value of ash content of this species in our report was 5.71%. The variation of ash content between the previous work (Aref et al., 2003) and the present study be due to sampling size determination, drying process duration (Stanturf et al., 2013), tree age (Kumar et al., 2010) or higher level of lignin and low mineral matter contents (Ajimotokan et al; 2019).

**3.5. Volatile matter**

The volatile matter value lies between 28.386% ± 0.66 (*Acacia nilotica*) to 34.461%±0.83 (Acokanthera *schimperi*) (Table 2). Volatile matter contents of charcoal produced from these species are significantly different α=0.05. The average volatile matter content of *Acacia seyal* reported in this study is 30.801% ± 0.31 comparable to the literature value of 28.08% for the species (Chiteculo et al., 2018; Aref et al., 2003). On the other hand, the highest value for the volatile matter is recorded for *A. schimperi* (Table 2). As the level of volatile matter increases, the calorific value decreases and vice versa. The same relationship was previously reported by (Mitchual et al., 2014). However, no particular trend is observed in comparing volatile matter content and the fixed carbon content with tree-age (Kumar et al., 2010). The PVM of the charcoal specimen as demonstrated in Table 2 varied between 27% and 33%. This result is like the PVM of the briquettes produced from agro wastes and wood residue from Nigeria (Falemara et al., 2018).

**3.6. Fixed Carbon**

In Table 2, the amount of fixed carbon of all the studied species is presented. There is a significant mean difference in the proportion of fixed carbon among charcoal samples used at α=0.05. Since the calculated F value is equal to 27.447, it is greater than the critical value of 3.478. The amount of fixed carbon content lies within the range of 51.611% ± 0.67(*Acokanthera*schimperi) and 63.725% ± 0.21 *(Acacia nilotica)*. *Acacia nilotica* has the highest carbon content and calorific value while *Acokanthera* schimperi has the lowest carbon content and calorific value. Although (Oyedun et al., 2012) argued that the average fixed carbon content of *Acacia seyal* is 58.76%, the result in the present study is 56.182%. Like calorific value, both carbonization temperature and environmental factors might be contributed to their small difference. The percentage of fixed carbon is also highest for *A. nilotica.* As the percentage of fixed carbon increases, its calorific value also increases. Their fixed carbon content also lies between 50% and 95 % (Liu, 2019). In the literature report (Ajimotokan et al., 2019; Aref et al., 2003) there is direct relationships between fixed carbon and calorific value.

### 3.7. Correlation

The correlation which exists between energy properties of charcoal samples are shown in Table 3.

**Table 3** Correlation matrix of mean energy properties of charcoal specimens

| Correlations | | | | | | |
|---|---|---|---|---|---|---|
| | | CV | PVM | PMC | PAC | PFC |
| Cv | Pearson Correlation | 1 | -.970** | -.992** | -.974** | .997** |
| | Sig. (2-tailed) | | .006 | .001 | .005 | .000 |
| | N | 5 | 5 | 5 | 5 | 5 |
| pvm | Pearson Correlation | -.970** | 1 | .978** | .913* | -.985** |
| | Sig. (2-tailed) | .006 | | .004 | .030 | .002 |
| | N | 5 | 5 | 5 | 5 | 5 |
| pmc | Pearson Correlation | -.992** | .978** | 1 | .936* | -.994** |
| | Sig. (2-tailed) | .001 | .004 | | .019 | .001 |
| | N | 5 | 5 | 5 | 5 | 5 |
| pac | Pearson Correlation | -.974** | .913* | .936* | 1 | -.962** |
| | Sig. (2-tailed) | .005 | .030 | .019 | | .009 |
| | N | 5 | 5 | 5 | 5 | 5 |
| pfc | Pearson Correlation | .997** | -.985** | -.994** | -.962** | 1 |
| | Sig. (2-tailed) | .000 | .002 | .001 | .009 | |
| | N | 5 | 5 | 5 | 5 | 5 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | |

The trend indicates that the increase of one of the energy properties increases or decreases the other energy properties. For instance, the increase of PMC, PAC or PVM decreases PFC and CV. Similarly, the increase of CV increases PFC but decreases PMC, PAC and PVM. The significance of determining PMC, PAC, PVM and PFC for finding out the calorific value were considered. It important to determine the fuel properties of not only fuelwood but also biomass, wood pellets and other fuel sources (Chiteculo et al., 2018; Ajimotokan et al., 2019; Koppejan et al., 2012; Mierzwa-Hersztek et al., 2019; Hasan et al., 2018). The study also examined the charcoal calorific value and other parameters against the community criteria used to judge the quality of charcoal, considering five preferred tree species for charcoal production. The corresponding charcoal of the five preferred tree species had varying amounts of calorific value. The calorific value, moisture content, ash content, volatile matter, and fixed carbon variation of the charcoal of various tree species were determined: *Acacia nilotica* followed by *Acacia etbaica* were the most preferred, as their charcoal contained the highest calorific value. Conversely, *Acokanthera schimperi* was least preferred due to its low calorific value charcoal. Although consumers' preferred quality charcoal based on their experience, their choice was vindicated by scientific measurement of the calorific value of the individual tree species from which the charcoal was produced.

## 4. Conclusions and Recommendations

Indiscriminate and unplanned mass cutting of tree species for charcoal production has caused biomass reduction, erosion, and air and water depletion. Therefore, charcoal production should be supported by scientific procedures to minimize environmental impact while achieving the population fuel needs. Charcoal calorific value is dependent on their moisture, volatile matter, and ash contents, and carbon variation. Among the five preferred tree species, *Acacia nilotica followed by Acacia etbaica* were the most preferred species as their charcoal contain the highest calorific values. Conversely, *Acokanthera schimperi* was the least preferred due to its low calorific value charcoal. Although consumers prefer quality charcoal based on their experience, their choices were vindicated by scientific measurement of the tree species' charcoal calorific value. Therefore, this study suggests that to continue with the charcoal demand all stakeholders should propagate the high caloric value tree species and promote energy-efficient technologies. This can be achieved by increasing the density of the most preferred tree species based upon their calorific value and introducing energy-efficient technologies.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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