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Production and Characterization of Charcoal Briquette from *Oxytenanthera abyssinica, Arundinaria alpina, Acacia melifera and Prosopis juliflora*

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Abstract

Production of sustainable and renewable energy source from locally available biomass feedstock's provides great opportunities to achieve sustainable growth and development in economic, social and environmental aspects for all nations across the globe. This study focused on production and characterization of charcoal briquettes from forest biomasses such as, *Oxytenanthera abyssinica*, *Arundinaria alpina*, *Acacia mellifera* and *Prosopis juliflora*, which were collected from different regions of Ethiopia (Amhara, Oromia and Somali). The experiment was conducted to determine moisture content (MC), volatile matter (VM), ash content (AC), calorific value (CV), fixed carbon (FC) and sulfur content (SC). The results were analyzed by using Statistical Analysis System (SAS) software. The analysis indicated that the effect of parameters considered in the experiment (i.e. Temperature, Binder ratio, Number of press and pressure) on the four species type and sample types were significant at level of probability, P = 0.0001. Maximum amount of MC was recorded for *P. juliflora* samples (i.e. Sawdust, Charcoal and Briquette) with respective values of 7.95%, 6.70 % and 6.88 %. The minimum amount of moisture was recorded on *A. alpina's* Sawdust with value of 5 % and *A. mellifera* Charcoal with value of 5.29 %. Moreover, the least amount of VM (17.31 %) was found in biomass briquettes produced from *A. alpina* species and have better fuel quality in comparison with the other species. The maximum CV was recorded on Densified Biomass Briquette (DBB) obtained from *A. alpina* and *P. juliflora* with the values of 7106.8 cal/gm and 6755.6 cal/gm, respectively. The study suggested that charcoal briquette produced from selected species exhibits good fuel characteristics (i.e. higher CV, less MC, and high level of FC, and low SC) in compliance with the international acceptable standard. Therefore, the obtained research output in the study encourages proper utilization of the biomass feedstock's for consumers and insure healthier environment via the supply of renewable source of energy

Keywords: Briquette, *Oxytenanthera abyssinica*, *Arundinaria alpina*, *Acacia melifera* and *Prosopis juliflora*

INTRODUCTION

Energy is vitally necessary to harness the life of human being and makes significant contributions for economic, social and environmental aspects of human development. The potential sources of this energy can be classified into two major categories, namely renewable and non-renewable energy sources. The sustainable and renewable energy sources are considered as a better option and preferable to the non-renewable sources because the non-renewable energy sources such as gasoline, coal, kerosene, diesel, etc. have no capability to be replenished and would be exhausted [1]. Furthermore, the environmental impacts as a result of emissions of greenhouse gases (GHG), CO_2, SOx, and NOx etc. during combustion and utilization of the non-renewable energy resources is a driving force towards the use of alternative, renewable and sustainable energy sources for domestic cooking, space heating, heat and power generation and heating of rural and urban households' particularly in developing countries. Among the renewable sources of energy, forest biomass feedstock's such as, *Oxytenanthera abyssinica*, *Arundinaria alpina*, *Acacia melifera and Prosopis juliflora* have become one of the most promising choices as cooking fuels due to their adequate availability and would have substantial roles in bioenergy (i.e. densified bio-briquettes) production processes [2]. However, the utilization of these biomass resources in their natural or raw form as fuel is difficult because of their very low bulk density, low calorific value (CV) and the excessive amounts of smoke they generate during combustion, difficult to handle, store and transport.

Application of effective and efficient briquetting technology is one of the ways of ameliorating calorific value (CV), the bulk density and handling techniques for such forest biomasses [3]. This requires appropriate densification of the subjected biomass resources in order to produce the densified bio-briquettes (DBB) with better handling characteristics and meliorated volumetric calorific value [4]. The production and processing of bio-briquettes from forest biomass resources illustrates the potential of proper technology for waste wood and fuel wood utilization [5]. Moreover, briquettes have several advantages over fuel wood in terms of convenience in use, cleanliness, greater heat intensity and qualified fuel characteristics, uniformity in size and requirement of relatively smaller space for storage and transportation [6-8]. During the utilization of charcoal briquette, there would be low emissions of the oxides of the combustible elements, for instances, the emission of CO_2 from the combustion of biomass feedstock's is equivalent to the amount of CO_2 absorbed during its growing cycle by means of photosynthesis; hence, the net CO_2 emission into the environment is approximately zero by mass [9-11]. The aim of the present study was production and characterization of charcoal briquette from *O. abyssinica, A. alpina, A. melifera and P. juliflora* and to evaluate its corresponding fuel properties of such as, physical properties, proximate analysis, and ultimate analysis, calorific value (CV).

MATERIALS AND METHODS

Description of Study Area

The study was conducted in *Pawe, Injibara and Borena* areas of Ethiopia. The study sites were selected based upon adequate resource availability; and considered as potential representative sites for the selected species across the regions of Ethiopia. The detail descriptions of study sites were expressed in Table 1 below.

Table 1: Description of the Study Sites

Study Site	Regional State	Altitude in masl.	Annual Rainfall in (mm)	Mean Annual Temperature in (^{0}C)	Literature source
Pawe	*Amhara region*	1050	1200-1585	16-32	[12]
Injibara	*Amhara region*	2540-3000	1813	16.25	[13-14]
Borena	*Oromia*	1350-1800	588	19	[15]
Afar	*Somali*	980	567	25.8	[15]

Sample Collection and Preparation

Sample of *P. juliflora* stem with 3-4 cm in diameter was collected from Afar region in February, 2013. Sample of *A. melifera* was collected from Borena region in 2015; and samples of bamboo species (*O. abyssinica,* and *A. alpina*) were collected from Pawe and Injibara areas in 2016. Then, the collected samples of specified species were chopped into suitable size, and then dried for further milling, washed in tap water to remove impurity from outer part of the stem and dried in oven dryer at a temperature of 65^{0}c for 48 hr. Then, the oven dried samples were milled using hammer mill into 2-3 mm in size, and further milled into mesh sizes of 0.25 mm and 1.4 mm using the disk mill.

Carbonization of Samples of the Specified Species' Strip Wood

The carburization of the strip wood (i.e. the disk mill with mesh sizes of 0.25 mm and 1.4 mm) was carried out in the furnace at temperature of 500 °C for 60 and 90 minutes, respectively. Then, the charcoal was removed immediately from the furnace and cooled under tap water. The cooled charcoal was spread over the floor and thereby dried in a naturally ventilated room with relative humidity (RH) of 86-89% at an ambient temperature of 25 °C – 30 °C for three days. The dried charcoal was cut into small strips manually by using sledge hammer to reduce sample sizes into appropriate mesh for making briquette.

Processing of Charcoal for Making Briquette

The prepared powder samples were taken turn by turn and proportionally mixed with the binder to make briquette. *Acacia seyal* gum Arabic was used as a binding agent for making briquette during the experimentation. The binder concentration of 5% was prepared and manually mixed with the prepared charcoal powder with solid to volume ratio in the range of 0.65 - 0.87 g/ml. The molds were then filled up to the edge of the mold tube and it was pressed by the Peterson Press. During the operation the pressure of machine (i.e. the Peterson Press) was reached maximum when the lever was at its lowest position; and then, dropped off before starting the next cycle. During the process, distilled water was squeezed out from the holes around the mold. Small time gap was maintained between two pressure cycles to facilitate the squeezing of water out from the briquette. Finally, 20 - 25% (wt.) moisture content of the densified biomass briquette (DBB) was obtained. A natural drying process method was used in the experiment until the moisture content of the DBB lies within the range of 12 - 15% [16].

Proximate Analysis of the Sawdust and Charcoal Briquettes Produced from Different Species

Determination of Moisture Content

Percentage of the moisture content (PMC) was determined using standard method of American Society for Testing Materials (ASTM D 4442-07) on basis of dry biomass was found by weighing samples of obtained briquette (W_1) and oven drying it at 105 °C and intermediate weight of sample was recorded in every 60 minutes until the constant weight was obtained (W_2). Then, the difference in weight (W_1 - W_2) was calculated to determine the sample's percentage moisture content using the following equation: -

$$\boldsymbol{PMC = \frac{W1 - W2}{W1} \times 100}$$

Where,

W_1 = Initial weight of sample before drying

W_2 = Final weight of sample after drying

PMC = Percentage Moisture Content

Determination of Volatile Matter

The percentage of volatile matter (PVM) content was determined using the standard method CEN/TS 15148. Two grams of sample was pulverized and oven dried at 105 ºC until its weight was constant. Then, the sample was heated at 550 ºC for 10 min and weighed after cooling in desiccators. The PVM was calculated using the following equation:

$$\boldsymbol{PVM = \frac{W1 - W2}{W1} \times 100}$$

Where,

PVM = Percentage of Volatile Matter

W_1 = Initial weight of sample

W_2 = Final weight of the sample after cooling

Determination of Ash Content

The percentage of ash content (PAC) was determined using CEN/TS14775 standard method. The percentage of ash content (PAC) was also determined by heating 2g of the pulverized sample in the furnace at a temperature of 550 ^oC for 4hrs and weighed after cooling in a desiccator to obtain the weight of ash. The PAC was determined using the following equation:

$$\boldsymbol{PAC = \frac{W2}{W1} \times 100}$$

Where,

W_1 = Initial weight of dry sample

W_2 = Final weight of ash obtained after cooling sample

PAC = percentage of Ash content

Determination of Fixed Carbon

The percentage of fixed carbon (PFC) was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) and percentage moisture content from 100 % as shown in the following equation:

Fixed Carbon = $\boldsymbol{100}\,\% - (\boldsymbol{PAC + PMC + PVM})$

Determination of Caloric value

The calorific value of briquette determines the amount of heat energy present in the material. The calorific value was determined in line with the moisture content, ash content, and volatile matter on the briquettes. The calorific value (kJ/kg) of the samples under test was calculated from the temperature rise of the briquettes when burnt and its heat capacity. A calorimeter apparatus was used to determine the calorific value of the produced briquettes.

Determination of Sulfur Content

Sulfur content was determined by Eschka method using ASTM-D 3177 standard. One-gram sample was put into a porcelain crucible and mixed with 3.00 g of Eschka mixture. The mixture was then covered with 1.00 g of Eschka mixture. The crucibles were then put in a muffle furnace and heated gradually to 800 °C for 60 minutes.

Data Analysis

A total of the four tree *species* (*O. abyssinica, A. alpina, A. mellifera and P. juliflora*) treatments with three replications and 6 measurement parameters were designed in the experiment. Statistical analysis of data was carried out using SAS Software, Version 9 and Microsoft Excel (2010) computer software. Means that exhibited significant differences were compared using Least Significant Difference (LSD) at ($P <0.001$) level.

RESULTS AND DISCUSSION

Variation in Proximate and Ultimate analysis on the Selected Species

The proximate analysis such as moisture content**,** volatile mater, fixed carbon and ash content of the four species where highly significant at probability, $P = 0.0001$, and affected by sample type and species type (Table 2); Whereas, the ultimate analysis (caloric value and sulfur content) among the selected species were also significant at level of probability, $P = 0.0001$, and affected by sample type and species type (Table 2). Moreover, the interaction effect among the selected species has shown a highly significant value on the proximate and ultimate analysis (Table 2).

Table 2: Analysis of Variance (ANOVA) for evaluation of test parameters on species of *Arundinaria alpina, Oxytenanthera abyssinica, Prosopis juliflor,* and *Acacia melifera*

Source of variation	*DF*	Mean square					
		MC	VM	FC	Ash	CV	SC
Species Type	3	4.25***	20.16***	108***	126***	505782***	0.08***
Sample Type	2	4.48***	10276***	8374***	85**	21785563***	0.12***
Species Type * Sample Type	6	3.79***	53.91***	104***	158***	674239***	0.02***
Cv		7.58	3.93	2.95	8.56	2.81	31.09
R^2		0.90	0.99	0.99	0.99	0.99	0.91

***= significant at $P < 0.0001$;**=significant at $P < 0.01$; significant at $P < 0.05$; and non-significant at $P < 0.05$

DF – Degree of freedom, MC – Moisture content, VM – Volatile matter, FC – Fixed carbon, CV – Calorific value, SC– Sulfur content, *Cv* - Coefficient of variance and R – Regression factor

The Interaction Effects of Sample type and Species type on Proximate Analysis of the Selected Species

Moisture Content

The interaction effect of the moisture content between the species types and sample type has shown significant value at $P = 0.001$, with the corresponding average moisture content of sawdust (6.82%), charcoal (5.60 %) and briquette (6.09 %), respectively. Regarding the species of *A. melifera* and *P. juliflora*, it has been shown that statistically similar and significantly higher values of moisture contents were recorded as 8.55% for sawdust of *A. melifera* and 7.95% for saw dust of *P. juliflora* (Table 3). Moreover, a relatively higher value of moisture contents were also obtained from samples of *P. juliflora* charcoal (6.70%) and its corresponding sample briquettes with value of 6.63%. On the other hand, statistically similar and minimum values of moisture contents were obtained from *A. alpina* sawdust with value of 5% and from sample of *A. melifera* charcoal (4.62%) (Table 3).

Volatile Matter

The interaction effect of volatile matter between the selected species types and sample types has shown that it is significant at level of probability, $P = 0.001$. The value of volatile matter content for the selected species varies in pre-carburization and post-carburization processes of biomasses. With this regard, it has been illustrated that maximum values of volatile matter content were obtained in the sawdust of *O. abyssinica* (71.95%), *A. alpina* (74.52%), *A. melifera* (72.11%) and *P. juliflora* (63.05%) with the corresponding mean value of volatile matter content of 70.41% in pre-carburization process. In this study, the recorded values of volatile matter content in the sawdust of the selected species were in compliance with the reports of 70.1% volatile matter content in the sawdust of tree species [17]. On the other hand, the minimum and statistically similar values of volatile matter content were recorded in post-carburization processes (i.e. in charcoal with mean value of 19.91% and in densified biomass briquettes with mean value of 20.17%) (Table 3).

When the volatile matter (VM) contents of biomasses compared transversally, it was demonstrated that for each sample types, significantly the least values of VM were observed on DBB of *A. alpina* (17.70%), *O. abyssinica* (19.18%) and *P. juliflor* (20.56%) (Table 3). The presence of low volatile matter in the resulting DBB enhances its combustion tendency in which a heterogeneous smokeless and flameless burning process takes place within the porous fuel or burning on the surface [18]. Moreover, the DBB sample with the minimum volatile matter content is anticipated to have the maximum energy value or calorific value [19]. Therefore, the presence of the least volatile matter content in the densified biomass briquette produced from sawdust of *A. alpina* species enables the briquette to have better fuel characteristics or fuel quality in comparison with the rest biomass briquettes of the selected species in the study.

Ash Content

The interaction effect of ash content among the selected species type and sample types is significant at level of probability, $P = 0.01$. In order to compare the amount of ash content transversally among the sample types in pre-carburization and post-carburization processes, it has been indicated that the minimum mean value of ash content (6.55%) was obtained in pre-carburization (i.e. in sawdust sample of the selected species) than in post-carburization processes (i.e. in charcoal and densified biomass briquette products with mean values of ash content 11.88% and 9.16%, respectively). Moreover, the minimum percentage of ash content were recorded for DBB produced from *P. juliflora*, *A. melifera* and *A. alpina* with their respective values of 3.56%, 6.56% and 5.18%; whereas, the maximum value of ash content (21.34%) was recorded in DBB produced from sawdust of *O. abyssinica* (Table 3).

The decrease in the amount of ash content in the biomass increases the quality of fuel [20-21]. Hence, it has been shown that the DBB produced from sawdust of species: *P. juliflora, A. melifera* and *A. alpina* relatively exhibits better fuel characteristics or fuel quality than the DBB produced from the sawdust of *O. abyssinica*. This study also indicated that the average value of ash content in Densified Biomass Briquette and carbonized sawdust for all selected species were in the range of 9.16 - 11.88 % (Table 3). The obtained values were much better than the reported values of average ash content by *Aries M. R.* [22], which were in the range of 14.6 - 31% for Feasibility of Biomass Briquette Production from Municipal Waste.

Fixed Carbon

Fixed carbon is the major quality measuring parameter that determines the energy behaviors in the production of densified biomass briquettes. It has been shown that the interaction effects of fixed carbon between sample types and species types is of significant value at level of probability, $P = 0.0001$. In the study, maximum value of fixed carbon was recorded on DBB made from species of *A. alpina* (71.17 %) and *P. juliflora* (70.22 %). The minimum percentage of fixed carbon was observed in DBB made from *A. melifera* and *O. abyssinica* with respective values of 56.60 % and 53.01 % (Table 3).

Table 3: Interaction effects between species type and sample type on proximate analysis of *Oxytenanthera abyssinica, Arundinaria alpina, Acacia melifera* and *Prosopis juliflora*

Sample Type	Moisture Content (%)			Volatile Mater (%)			Fixed Carbon (%)			Ash Content (%)		
	Sawdust	Charcoal	Briquette	Sawdust	Charcoal	Briquette	Sawdust	Charcoal	Briquette	Sawdust	Charcoal	Briquette
Oxytenanthera abyssinica	5.79d^{e}	5.2ef^{g}	5.71^{def}	71.95^{b}	14.29^{h}	19.18^{fg}	19.07^{f}	62.31^{c}	53.01^{e}	3.53^{h}	18.43^{b}	21.34^{a}
Arundinaria Alpina	5f^{g}	5.89^{cde}	6.42^{bcd}	74.52^{a}	20.43^{ef}	17.7^{g}	18.6^{f}	64.23^{bc}	71.17^{a}	1.97^{g}	9.45^{e}	5.18^{g}
Acacia Melifera	8.55^{a}	4.62^{g}	5.67^{def}	72.11^{ab}	21.82^{de}	20.72^{def}	17.51^{f}	58.37^{d}	56.6^{d}	4.05^{gh}	14.47^{d}	6.56^{f}
Prosopis Juliflora	7.95^{a}	6.7^{b}	6.63^{bc}	63.05^{c}	23.09^{d}	20.56^{ef}	12.28^{g}	65.04^{b}	70.22^{a}	16.66^{c}	5.16^{g}	3.56^{h}
Mean	6.82^{a}	5.60^{b}	6.11^{ab}	70.41^{a}	19.91^{b}	20.17^{b}	6.55^{b}	11.88^{a}	9.16^{a}			

Means followed by the same letters under the same column are statistically non-significant at level of probability, $P = 0.05$.

Calorific Value (Heating Value)

The calorific value is the principal quality index for fuels [16]. The calorific value of densified biomass briquettes relies on the moisture content, ash content and fixed carbon content [23] in relation with other factors such as, species types, raw materials' pretreatment, types of binding agent, particle's size, solid to liquid ratio and the nature of briquetting machine. Hence, mixing of pretreated biomass species with appropriate ratio of binding agent is helpful to produce the DBB with better fuel characteristics [24].

The interaction effect among the selected species types and sample types with respect to the calorific values of DBB has shown significant value at level of probability, $P = 0.001$. In the study it has been found that the DBB produced from species of *A. alpina* and *P. juliflora* with respective calorific values of 7167 cal/gm and 6979 cal/gm exhibits good fuel characteristics in comparison with DBB produced from species of *A. melifera* (6791 cal/gm) and *O. abyssinica* (6140 cal/gm) (Table 4). Moreover, the observed calorific values of DBB showed an improvement in fuel quality when relatively compared with the previous research finding the value of 4641.14 cal/gm [25].

Sulfur Content

The sulfur content in the produced DBB contributes to emission of compounds of SO_x into atmosphere during utilization of the fuel. The interaction effect among species type and sample type on the amount of sulfur content has shown significant value at level of probability, $P = 0.001$. The overall mean value of DBB produced from all species was recorded to be 0.05 %. This value was relatively lower than the value of sulfur content in charcoal (0.16 %) and saw dust (0.25 %) (Table 4). In addition, statistically similar values of sulfur content were found in DBB (i.e. 0.09% from *O. abyssinica*, 0.06% from *A. alpina*, 0.04% from *A. melifera* and 0.02% from *P. juliflora*) ranging from mean value of 0.02 – 0.05 % by dry matter weight. The obtained values of sulfur content in the experiment were lower when compared to fuels of other biomass briquettes such as mixed paper, bituminous coal and refuse-derived fuel [26, 27, 16]; and it was in compliance with the DIN 51731 standards of < 0.3% and < 0.08%, respectively.

Table 4: Interaction effects between species type and sample type on ultimate analysis of *Oxytenanthera abyssinica, Arundinaria alpina, Acacia mellifera and Prosopis juliflora*

	Calorific Value (cal/gm)			Sulfur Content (%)		
Sample Type	Sawdust	Charcoal	Briquette	Sawdust	Charcoal	Briquette
Oxytenanthera abyssinica	4390^{g}	6485^{d}	6140^{e}	0.24^{b}	0.37^{a}	0.09^{cd}
Arundinaria alpina	4737^{f}	6558^{cd}	7167^{a}	0.17^{bc}	0.39^{a}	0.06^{cd}
Acacia melifera	4587^{fg}	6071^{e}	6791^{bc}	0.22^{b}	0.23^{b}	0.04^{d}
Prosopis juliflora	3393^{h}	6225^{cd}	6979^{ab}	0.02^{d}	0.02^{d}	0.02^{d}
Mean	4277^{c}	6335^{b}	6769^{a}	0.16^{b}	0.25^{a}	0.05^{c}

Means followed the same letters under the same column are statistically non-significant at level of probability, $P = 0.05$.

CONCLUSION

The increases in number of human population and depletion of non-renewable energy resources have necessitated the exploration of sustainable, renewable and environmentally friendly energy sources. Another driving force behind this research is the need to address the environmental consequences and health hazards associated with the use of solid fuels such as fuel wood and coal and also to develop an effective means of recycling and managing forest products. The most relevant findings in the present work were production of environmentally friendly solid biofuel - charcoal briquettes from *Oxytenanthera abyssinica, Arudinaria alpine, Acacia mellifera and Prosopis juliflora* and characterization (proximate and ultimate analysis) of the corresponding products respectively. The domestic use of charcoal briquettes in low-income families provides great opportunities as a sustainable renewable and alternative energy source that could be further developed as it allows for the economic revaluation of forest biomass and wood waste and the mitigation of greenhouse gas emissions. The charcoal briquette produced from the studied species has observed that with a higher calorific value, less moisture content, and high levels of fixed carbon, and low sulfur content were found on the studies are accordingly listed as follows within the international acceptable limit.

1. *Arundinaria alpina*
2. *Prosopis juliflora*
3. *Acacia mellifera* and
4. *Oxytenanthera abyssinica*

Therefore, the use of these types of charcoal briquette is environmentally friendly, release lesser carbon to the atmosphere, reduce health hazard associated with the use of fuel wood and reduce deforestation and its attended complications and used for the cost savings involved.

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