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Research Article

Utilization of *Tetrapleura tetraptera* Waste for Energy and Climate Change Mitigation

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Abstract
Charcoal production as practiced in Ghana contributes greatly to the deterioration of the environment through deforestation. *Tetrapleura tetraptera* is used as a spice and thickener as well as syrup and condiments among others. It now finds wide usage in the alcoholic and non-alcoholic beverage industries. In these operations, huge quantities of waste are generated. The objective of this work was to convert the waste into energy for climate change mitigation. The woody fruit residue of *T. tetraptera* and wood cut from the forest were carbonized into charcoal in a steel carbonizer at a temperature of 500^0C. Charcoal yield, physicochemical and energy properties were determined. The quantity of trees that would have been cut from the forest to produce the same amount of charcoal as obtained from the woody fruit residue was determined. The charcoal yield from *Cylicodiscus gabonensis* and *Acacia nilotica* was 25% each whilst the yield from *T. tetraptera* woody fruit residue was 30%. *T. tetraptera* fruit residue was found to be a high yielding charcoal. It showed quality charcoal in terms of high calorific value and fixed carbon content comparing with the preferred wood species investigated. The use of *T. tetraptera* fruit waste is therefore a suitable sustainable option for charcoal production and this option will greatly reduce the environmental pollution caused by the indiscriminate dumping of the waste.

Keywords
Tetrapleura tetraptera — charcoal — environmental pollution —carbonization — energy

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Content

1. Introduction

The majority of energy interventions in Ghana have been in the traditional and renewable energy sub-sector. The bulk of energy supply in Ghana is met from biomass mainly firewood and charcoal (64%), petroleum (27%) and electricity (9%). Wood fuels account for about 70 percent of total primary energy supply and about 60 percent of the final energy demand, providing energy for domestic cooking and heating [1, 2]. According to Derkyi et al. [3], close to 90% of households in Ghana use firewood or charcoal for cooking. It is also used to provide process heat in the wood processing industries for drying [4]. Ghana's Forest Policy objective is to manage, protect, conserve and develop her forest in order to ensure sustainable wood (as well as non-timber forest products) production and utilization to optimize the economic, social and environmental benefit, to the people and to provide sustainable support for the country's forest-based industries [5].

Carbon (C) emissions from deforestation and degradation account for about 20% of global anthropogenic emissions [6]. Deforestation is the single largest source of land-use change emissions, resulting in emissions of more than 8Gt CO2/yr [7]. Tropical deforestation has been offset to some extent by the increase in world's temperate and boreal forests, but the overall size of global forests is declining. Estimated net annual decline in the forest area globally in the 1990s was 9.4Mha (million hectares), representing the difference between the annual deforestation of 14.6Mha and the annual afforestation of 5.2Mha [8]. The Stern Review [9] reinforces the finding that forest conservation, afforestation, reforestation and sustainable forest management can provide up to 25% of the emission reductions needed to effectively combat climate change. The international carbon market is a promising channel for improving livelihood opportunities for the rural poor in the forest areas [10].

According to Kammen and Lew [11], the production, transport and combustion of charcoal constitute a critical energy and economic cycle in the economies of many developing countries. Wood fuel extraction and supply is key income source for a wide range of stakeholders and forms an important source of livelihood for most rural people and an increasing number of urban dwellers who engage in the charcoal and fuel wood trade.

Ninety percent of the wood fuel supply in Ghana is derived directly from the natural forest [12]. The over exploitation of traditional hard wood species such as Kane (*Anogeissus leiocarpus*), Odum, Mahogany, Shea, Danta has resulted in scarcity of these species. This has led to charcoal producers switching to new soft wood species which produces lots of charcoal dust and also burn quickly, in the process generating lots of ashes.

Charcoal production as practiced in Ghana contributes greatly to the deterioration of the environment through deforestation. In Ghana, 90% of the fuelwood is obtained directly from natural forests with an annual deforestation rate of 3% [13]. The use of woodfuel is expected to be more than double between 2010 and 2020 [13]. With increasing household income and urbanization, it is expected that a larger number of households will switch to using charcoal instead of firewood. The detrimental effects of charcoal production on the environment have raised a growing concern among policy makers, environmentalists and local authorities responsible for the management of forest resources. Previously most wood supply for charcoal production was from off-reserve sources. However, with the scarcity of the preferred species, forest reserves are also being targeted for illegal charcoal production.

Tetrapleura tetraptera is a four winged fruit. Two of the wings are soft whilst the other two are hard and woody. The fruit is used as a spice and thickener as well as syrup and condiments among others. It now finds wide usage in the alcoholic and non-alcoholic beverage industries. In these operations, huge quantities of waste are generated. The objective of this work was to convert the waste into energy for climate change mitigation.

2. Materials and Methods

2.1 Materials

Wood species *(Acacia nilotica and Cylicodiscus gabonensis)* were cut from the forest. *Tetrapleura tetraptera* fruit waste was collected from processing centers. Annual production of the fruit waste was estimated from four processing centers in Ghana. Moisture content of the species was determined before carbonization.

2.2 Carbonization

The woody fruit residue of *T. tetraptera* was carbonized into charcoal in a steel carbonizer at a temperature of 500^0C. Wood cut from the forest was also carbonized into charcoal at the same conditions. Charcoal yield from the woody fruit residue was determined as a ratio of the weight of charcoal produced to the weight of un-carbonized woody fruit residue. Charcoal yield from wood (cut from the forest) was similarly obtained. The average percentage charcoal yield from wood and the amount of charcoal produced from woody fruit residue were used to estimate the quantity of trees that would have been cut from the forest to produce the same amount of charcoal as obtained from the woody fruit residue: The stratification of the data sample was done as follows:

$$W_{fc} = W_w \times Y_c --------------(1)$$

- W_{fc} = weight of woody fruit residue charcoal
- W_w = weight of wood cut from forest for charcoal production
- Y_c = % yield of charcoal from wood

2.3 Physicochemical and Energy characterization

Physical properties (density, moisture content) and chemical properties (volatile matter, ash content, fixed carbon content) as well as energy value of the charcoal produced were determined by standard analytical methods, ASTM and AOAC. For moisture content determination, samples were heated in an aerated oven at 105^oC till constant weight was obtained. Moisture content (MC) was calculated as a proportion of initial mass. Density was obtained as mass of oven-dried charcoal to volume of oven-dried charcoal. The volatile matter (VM) was obtained as mass loss after combusting the charcoal sample at 950^oC in a furnace for 15 min. The charcoal samples were combusted at 750^oC for 6 h and the ash so produced weighed and the weight expressed as a percentage of the original mass of charcoal to furnish the ash content. The fixed carbon content (FC) was obtained as difference: FC = 100% - (MC + VM + Ash) %. The calorific values were determined using the bomb calorimeter. Each experiment was done in triplicate and the average value determined.

Water boiling test was performed as follows: For each charcoal sample, 300g was ignited with 5ml kerosene to boil 2L water for 30 min. Burning rate (grams of charcoal consumed per unit time) and work done (grams of water evaporated per grams of charcoal used) were determined. Each experiment was done in triplicate and the average value determined.

2.4 Data Analysis

The SPSS 20 software package was used to perform univariate analysis of variance (ANOVA) and least significance difference (LSD) in the charcoal properties of the different wood species determined at the 5% level of significance.

3. Results

The moisture content of the wood species before carbonization is depicted in Figure 1. In this study, the moisture content of the wood species before carbonization was not significantly different at the 5% level of significance (Figure 1). The charcoal yield from *C. gabonensis* and *A. nilotica* was 25% whilst the yield from *T. tetraptera* woody fruit residue was 30%. Table 1 depicts the physicochemical properties (density, moisture content, volatile matter, ash content and fixed carbon content)

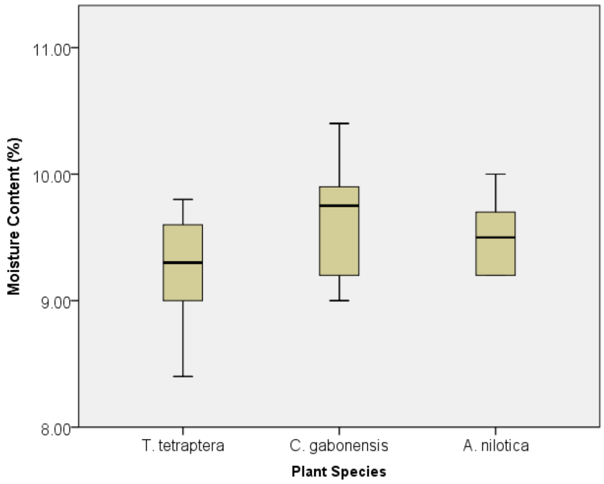

Figure 1. Moisture content of wood species before carbonization.

and calorific values of charcoal produced from the three wood species, whilst Table 2 depicts the water boiling properties (burning rate and work done) of the wood species. Figure 2 and Figure 3 are the pictures of the un-carbonized and carbonized *T. tetraptera* fruit waste.

Table 1. Physicochemical properties and calorific values of three wood species

Species	Density (g/cm3)	MC (%)	VM (%)	ASH (%)	FC (%)	CV (Kcal/g)
T. tetraptera	0.33 ± 0.01^{a}	0.5^{a}	16.67 ± 0.20^{a}	4 ± 0.2^{a}	78.83 ± 0.75^{a}	7.80 ± 0.20^{a}
C. gabonensis	0.48 ± 0.01^{b}	0.8^{b}	21.15 ± 0.20^{b}	3.5 ± 0.1^{b}	74.55 ± 0.92^{b}	7.20 ± 0.27^{b}
A. nilotica	0.35 ± 0.01^{a}	0.6^{c}	20.0 ± 0.20^{c}	$3.7 \pm 0.2^{a},^{b}$	75.43 ± 0.68^{b}	$7.38 \pm 0.35^{a},^{b}$

Source: Values bearing the same letter in a column are not significantly different at the 5% level by LSD.

Table 2. Water boiling properties of three wood species.

Species	Burning rate (g/min)	Work done (g H_2O/g fuel)
T. tetraptera	7.85 ± 0.70^{a}	2.33 ± 0.14^{a}
C. gabonensis	7.10 ± 0.95^{b}	2.45 ± 0.15^{a}
A. nilotica	7.56 ± 0.84^{a}	2.38 ± 0.20^{a}

Values bearing the same letter in a column are not significantly different at the 5% level by LSD.

Figure 2. Un-carbonized *T. tetraptera*fruit waste

Figure 3. Carbonized *T. tetraptera*fruit waste (Charcoal)

4. Discussions

The moisture content of wood before carbonization affects the yield and sometimes the rate of carbonization [14]. In plant materials, cellulose, hemicellulose, lignin, organic acids and minerals comprise about 90 – 95 % of the biomass [15, 16]. In the process of carbonizing lignocellulosic materials, depolymerization, cracking and dehydration of lignin occur. During this biomass conversion at low temperatures, cellulose is converted to anhydrocellulose whilst at increased temperatures cellulose gets depolymerized and produces levoglucosan. It has been determined that anhydrocellulose yields better charcoal than levoglucosan [17, 18]. Some good correlations between charcoal yield and cellulose and lignin in plant samples have been reported [19, 20, 21, 22]. A high lignin content gives a high yield of charcoal. Therefore, mature wood in sound condition is preferred for charcoal production. Dense wood also tends to give a dense, strong charcoal, which is also desirable. However, very dense woods sometimes produce a friable charcoal because the wood tends to shatter during carbonization. From Table 1, it can be observed that the novel energy material (*T. tetraptera* woody fruit residue) had a comparative fixed carbon content to the high density and moderately high density wood species *C. gabonensis* and *A. nilotica* respectively. Charcoal produced from *T. tetraptera* woody fruit residue had a similar calorific value as that of *A. nilotica* and significantly higher calorific value than *C. gabonensis* charcoal. The least significant difference (LSD) revealed that the burning rate and work done by each fuel were not significantly different at the 5% level (Table 2). A soft burned charcoal has a high volatile matter and a low fixed carbon content and tends to smoke during burning. It is fairly resistant to shattering and thus transports and handles without producing very many fines. Hard burned charcoal, on the other hand, is high in fixed carbon content, low in volatiles, much more friable and burns cleanly. High calorific value and high fixed carbon content are desirable for a good charcoal [23], and these were observed for the charcoal produced from *T. tetraptera* fruit waste.

In Ghana it has been determined that more wood fuel is consumed than any other energy source, followed by petroleum and electricity. It has also been documented that about 1.29 million Ghanaian households use charcoal for cooking, or about 31% of the total number of households in Ghana [24]. According to the FAO, Ghana has the highest per capita wood energy demand in all of West Africa and is among the top two for charcoal. It has been estimated that about 69% of all urban households in Ghana use charcoal.

The adoption of novel *T. tetraptera* woody fruit residue on the well-established wood-fuel market, can be expected as it can favourably compare with traditional wood charcoal species in price and in quality. The total wood fuel consumption in 2000 in Ghana was approximately 18-20 million tonnes of solid wood equivalent, with annual charcoal consumption of about 1.1 million tons [24]. Annually in Ghana, approximately 333,000 tons of fruit waste (*T. tetraptera* woody fruit residue) was estimated to be generated. The waste is either burnt or dumped indiscriminately causing serious environmental pollution. The waste generated translates to 99,900 tons of charcoal (ie. 30% charcoal yield). Since the yield of charcoal from wood was 25%, then the potential annual production of 99,900 tons of *T. tetraptera* woody fruit residue charcoal, potentially saves 399,600 tons of trees/year in the forest (equation 1). This will minimize deforestation and contribute to climate change mitigation. It must be noted that over the life of the *T. tetraptera* tree, fruits will almost always be regenerated making it a sustainable source of energy.

5. Conclusion

T. tetraptera fruit residue is a high yielding charcoal. It showed quality charcoal in terms of high calorific value and fixed carbon content with low moisture content comparing with the preferred wood species investigated. The use of *T. tetraptera* fruit waste is therefore a suitable sustainable option for charcoal production and this option will greatly reduce the environmental pollution caused by the indiscriminate damping of the waste. A suite of potential bioenergy policies including a displacement of fossil fuels with a percentage of biofuels produced from forest and agricultural biomass and incentives for bioenergy producers could ensure minimal use of fossil fuels resulting in climate change mitigation. It is expected that these policies will not only impact the forest sector by creating demand for forest biomass but other sectors of the economy through factor markets. These results may provide valuable information for policy makers in their decision-making.

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