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Original article

Relationship Between Chemical Composition and User Perception on Wood-Charcoal Species Preference in Bauchi Metropolis, Nigeria

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Abstract

Urban least well-off and poor households in Bauchi Metropolis face challenge of accessing affordable, reliable and sustainable cooking and heating fuel supplies. As such, the urban least well-off and poor have leveraged their energy demands on use of wood-charcoals, which produced and utilise through mostly informal supply and demand chains that are associated to low efficiency in production methods and ineffective household utilisation factors that contribute to environmental and health dilapidation. This study sought to establish the relationship between physico-chemical characteristics of wood-charcoals commonly produced and utilised and users' perception on charcoal species preference in Bauchi Metropolis. A laboratory experiment was conducted to determine the physico-chemical characteristics of the wood-charcoals. This was done prior to the field survey on perception preference to users to collaborate their views or otherwise on the burning and fuelling characteristics of the examined wood-charcoal species. A survey was undertaken using questionnaires to assess the users' perception preference on the commonly used wood-charcoal species in terms of their solidity, ease of ignition, heat output intensity, rate of devolatilisation, burning time, ash generation and smoke. Of all the wood-charcoal species examined, *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) had low moisture contents (4.17, 4.60%, respectively), high calorific value (33.58, 30.09 MJ/kg, respectively) and low ash content (5.35, 6.51%, respectively) together with their glassy index evident by high aluminium, potassium, and silicon contents, indicating that these charcoal species have high-quality combustion and fuel outputs compared to other charcoal species with least combustion and fuel characteristics. Despite these qualities, these species can't provide cleaner energy that could cut pollutant emissions, and at the same time bring huge environmental quality and health benefits, yet users perceptibly give preference to these charcoal species based on their combustion and fuelling performance impression.

Keywords: Wood-charcoal, users' perception, combustion and fuel.

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INTRODUCTION

In the absence of equable and widespread distribution of modern energy service in tropical Africa, urban households particularly the low in-come earners and urban poor are facing severe challenge of finding affordable, reliable and sustainable energy supplies for cooking and other domestic applications. This has resulted in investing effort to utilise firewood and wood-charcoals which are abound in this region. However, wood-charcoal is in high demand in many parts of Africa as it contains energy that doubles that of ordinary firewood and thus burns much hotter (Ekouevi and Tuntivate, 2011). Besides, wood-charcoal is cheap, readily available and very affordable compared to other sources of energy such as electricity, kerosene and cooking gas and therefore wood-charcoal is inexpensive for many Africans. Unlike other fuels which often require vast distribution networks before they get to the final consumers and as such wood-charcoal is largely produced and sold locally. Because wood-charcoal is much lighter in weight than firewood, it is economically cheaper to transport over longer distances. Charcoal takes less room and can be stored for a very long period without damage or spoilage, which is unlike firewood, it cannot be attacked by insects and fungi that reduce effectiveness and value.

For many least well-off and urban poor, wood-charcoal provides a reliable, convenient and accessible source of energy for cooking at a stable cost. While electricity and gas may be considered the most desired cooking fuels in urban areas, even if these are available most poor households cannot afford both the energy resources and the devices required to use these forms of energy. Many households, therefore, turn to using kerosene or wood-charcoal. Since kerosene is not always available or too costly for many, this has put wood-charcoal in the forefront as the most readily available fuel (Mugo and Ong, 2006). Therefore, charcoal as a wood-based biomass is becoming the dominant alternative source of energy in tropical Africa, where significant proportion of both rural and urban households rely on it far more than any other energy sources (UNDP and WHO, 2009; Van-Beukering *et al*., 2007). According to the United Nations Environment Program (UNDP, 2009; AFREA/World Bank, 2011), firewood and charcoal alone provide more than 40 percent of energy used in tropical Africa. In fact, around 81 percent of households on this region depend on wood and charcoal as a primary energy source.

In Bauchi State, Southern Local Government Areas like Bauchi, Toro, Ganjuwa and Ningi are well known as the major wood-charcoal production base, where many local communities have perfected the technology of wood-charcoal production and made it as an enterprise. Although charcoal can be made from both hard and soft wood but using the right type of wood often determines the quantity and quality of charcoal produced. Based on the producers and consumers perceptions, the hard-wood species produces better charcoals and consequently is more preferred and mostly used in charcoal production in these areas. This is because, to the producers, it fetches higher demand and price in the market as it does not break easily and for the consumers, has a higher energy content than charcoal made from soft-wood. It is for these reasons; both the producers and end-users perceptibly give preference to such wood-charcoal species based on solidity (hardness and heaviness) and burning performance. Therefore, the aim of this article is to establish relationship between chemical composition and user perception on wood-charcoal species preference with respect to burning performance. This approach could provide important insights that improve and expand current understanding of this energy demand-user perception nexus, which could expunge hindrances and provide dictate platform for energy policy and planning required for sustainable wood-charcoal production and utilisation.

MATERIALS and METHODS

Description of the study area

This study was conducted in Bauchi State, North-eastern Nigeria, where wood-charcoal samples were collected from the major sites of charcoal production zones in the Southern part of the State that covered four Local Government Areas namely Bauchi, Ganjuwa, Ningi and Toro. The State is strategically located between latitude 9.3^0 and 12.3^0 North of the Equator. Longitudinally, the State lies between longitudes 8.50^0 and 11^0 East of the Greenwich Meridian which gives it a mixed climatic zone. The State is one of the few states in Northern Nigeria that has two distinctive ecological zones; namely, the Sudan savannah and the Sahel savannah. The Sudan savannah covers the Southern part of the State where the vegetation gets richer and richer towards the South, whereas the Sahel also known as the semi-desert vegetation covers the Western and Northern parts of the State, which is characterized by isolated strands of horny shrubs and sandy soils. On the other hand, the user perception preference investigation was carried-out in Bauchi Metropolis, Bauchi Local Government of Bauchi State of Nigeria. Bauchi Metropolis is a residential area in the Eastern part of Nigeria. It is the capital of Bauchi State; it is located at the North edge of Jos Plateau at an elevation of 616m (Anonymous). The study area represents the part of the topographic map of Bauchi North-East sheet 149 as produced by Federal Survey of Nigeria and it falls within N-E part of the map basement complex (Enwerem, 2006). It is located on the coordinate $10^o.15 – 10^o.22$ Northern and $9^o.45 – 9^o.55$ Eastern (Bauchi State Ministry of Land and Survey, 2015).

Wood-charcoal samples collection and preparation

The samples of the most common wood-charcoal species produced in Bauchi state were collected from the major sites of charcoal production zones in the southern part of the state. The wood-charcoal species collected were: *Anogeissus leiocarpus* (Marke), *Butyrosperum paradoxum* (Tabo), *Combretum lamprocarpum* (Zindi), *Ficus platyphylla* (Ganji) and *Pakia biglobosa* (Dorawa). All the lump samples were collected in polyethylene bags and subsequently taken to laboratory where the samples were thoroughly prepared, milled or not milled and stored in air-tight plastic bags before taking for analysis of combustion and fuel related parameters.

The analysis of wood-charcoal samples

The densities of the charcoal samples were determined using water displacement method. Density was calculated from the ratio of the mass to the volume of the charcoal in accordance with the method used by Rabier *et al.* (2006). Carbon, hydrogen, and nitrogen content in the samples were analysed in accordance with BS EN ISO 16948:2015, which is specifically designated for solid biofuels (Diarmaid *et al*., 2018). Oxygen and sulphur contents in the samples were analysed on two separately configured CE instruments EA 1110 Elemental Analyser (Thermo Scientific) with aid of Thermo EAger Xperience software. The analysis of chlorine was conducted according to BS EN standard method BS EN ISO 14582:2016, in which a weighed sample was combusted in pure oxygen in an enclosed vessel (oxygen flask). The gases were absorbed in a suitable absorbent solution within the flask. The solution was washed from the vessel and made up to a known volume and the chloride was quantitatively determined by ion chromatography. The instrument software compared the chloride peak to a series of known standard materials (after calibration) and generated a report for the chlorine content on a weight basis. Proximate analyses were also conducted according to BS EN standard methods with the following adaptations. The BS EN ISO 18134-2:2017 method was implemented for moisture content, where a sample was placed into a suitable prepared and weighed tray and reweighed, which was then dried at 105 ºC to constant weight and the total moisture/dry solids content was calculated from the reduction in weight. The ash content of a dried sample was determined gravimetrically as prescribed by BS EN ISO 18122:2015, by which a sample was weighed into a prepared ash crucible and placed in a furnace. The furnace was heated to 550 ºC ±10 ºC where the temperature was maintained. Following combustion, the crucible and sample are removed, cooled in a desiccator and reweighed. BS EN ISO 18123:2015 standard method was used for volatile matter, where a dried sample was placed in a suitable crucible fitted with a close-fitting lid. The crucible and sample were weighed and heated in a furnace with a limited air throughput at a temperature of 900 ºC ±10 ºC for 7 minutes. The sample and crucible were re-weighed, and the volatile matter content determined by difference. Both ultimate and proximate analyses were performed at least in duplicate. Calorific value of the samples was determined in an Isoperbol calorimeter by burning in pure oxygen in a combustion bomb. Based on BS EN 14918/BS EN 15400 standard method, a weighed sample was placed in a combustion bomb which was then pressurised to 30bar with oxygen. A calorimeter bucket was filled with a known amount of deionised water which is placed in the calorimeter and the bomb placed in the bucket. The system was allowed to equilibrate and the bomb fired by electrical connection. The difference in temperature of the water in the calorimeter bucket caused by the ignition of the material in the bomb was measured and the calorific value calculated as heating value for each sample. The fixed carbon contents of the samples were determined by deducting the sum of % volatile matter, % ash content and % moisture content from 100 as presented in equation (1).

Fixed carbon content = [100 ─ (% VM + % AC + % MC)] (1)

The elemental analysis of Ca, K, and Si in the wood-charcoal samples was determined using instrument EDX 3600B Energy Dispersive *X*-ray Fluorescence Spectrometer (EDXRF). The wood-charcoal samples were pulverised to fine homogenous sizes, which were then pelletised for analysis. The average of values was determined on weight basis (Elsayed *et al*., 2016; Elsayed *et al*., 2014).

User perception on wood-charcoal species preference investigation

The user perception on wood-charcoal species preference was conducted in the core of Bauchi Metropolis at the most popularly known and populated areas, where 500 users were sampled purposively. These areas comprised of Muda-Lawal market, Gwallaga, Gwabba, Nassarawa-Jahun, Wunti, Kobi, Bakaro, Karofi, Bakin-kura and Shekal, where majority of the urban least well-off and poor are residing as well as use of wood-charcoal is prevalent. The potential users sampled included wood-charcoal vendors, households, maize roasts, roadside and market food vendors. Purposive sampling technique was employed and survey was conducted with structured questionnaires. A pilot study was carried out to test the reliability of the construct of the questionnaire using Cronbarch's Alpha test to measure what is intend for and satisfy its validity through the information extracted from the respondents' response. Questions of critical importance which the potential users responded to include solidity (hardness and heaviness), ease of ignition of the solid bio-fuels, the effect of the burning rate of the wood-charcoal species, heat output, rate of devolatisation (how fast the wood-charcoals burnt), burning time or combustibility rating (how long the wood-charcoals burnt before restocking when they are used in cooking and heating), sparking ability (whether or not the wood-charcoals produce sparks when burning), smoke generation and any other effects regarding the burning of the wood-charcoals. The results of the survey were analysed using descriptive analysis tools in the Statistical Package for Social Scientists (SPSS) version 21.0.

RESULTS and DISCUSSION

Table 1 represents the proximate, ultimate and EDXRF-elemental analyses of all the attracted wood-charcoals, which represent the physico-chemical composition of the biofuels that describe their combustion and fuel characteristics.

General analysis

The density, ash, moisture, volatile matter and fixed carbon contents constitute the proximate parameters of solid fuels. Among the tested wood-charcoals, density values ranged from 0.12 to 0.36, of which *Ficus platyphylla* had the highest value of 0.36 gcm^{-3}, followed by *Anogeissus leiocarpus* with density of 0.28 gcm^{-3} and the least values recorded were for *Combretum lamprocarpum*, *Butyrosperum paradoxum* and *Pakia biglobosa* with 0.21, 0.17 and 0.12 gcm^{-3}, respectively. Density of a solid fuel describes the sponginess and penetrability that exists between inter and intra particles, which enable easy infiltration of oxygen and out flow of burning solid fuel (Adegoke and Lawal, 1997). It is also a physical property that accounts the geometry (bulkiness and packing orientation) of a solid fuel (Sotannde *et al*., 2010). Therefore, the high porosity index of *Ficus platyphylla* and *Anogeissus leiocarpus* could be one of the responsible factors that made them to exhibit sluggish burning rate than other bio-energy sources with low densities. In addition, the high density of wood-chacoals of *Ficus platyphylla* and *Anogeissus leiocarpus* provide them sufficient hardiness to withstand shocks of uploading, transportation, downloading and packing for storage. The moisture percentage contents of the wood-charcoal species originally varied from 4.17 to 6.63%, of which *Combretum lamprocarpum* (Zindi) had the highest value of 6.63% and *Ficus platyphylla* (Ganji) recorded the lowest value of 4.17%.

Table 1. Wood-charcoals chemical composition and heating value data.

Content	**Units**	***Anogeissus leiocarpus* (Marke)**	***Butyrosperum paradoxum* (Tabo)**	***Combretum lamprocarpum* (Zindi)**	***Ficus platyphylla* (Ganji)**	***Pakia biglobosa* (Dorawa)**
Density	gcm^{-3}	0.28	0.17	0.21	0.36	0.12
Moisture	wt%	4.60	5.66	6.63	4.17	5.10
Ash	wt%	6.51	12.61	10.11	5.35	16.91
Volatile matter	wt%	17.79	31.35	26.59	13.59	34.59
Fixed carbon	wt%	71.10	50.38	56.67	76.89	43.40
C	wt%	76.13	73.55	70.26	76.59	64.38
H	wt%	3.55	3.13	2.63	4.08	2.83
O	wt%	18.90	15.66	10.25	16.29	12.38
N	wt%	0.43	0.26	0.22	0.52	0.32
S	wt%	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cl	wt%	0.04	0.03	0.02	0.05	0.01
Calorific value	MJ/kg	30.09	23.14	25.36	33.58	26.71
Al	wt%	1.05	0.56	0.54	1.04	0.49
Ca	wt%	8.21	28.05	17.09	15.92	30.96
K	wt%	8.12	2.28	2.69	8.36	4.64
Si	wt%	1.16	0.53	0.55	1.36	0.46

The presence of moisture in solid bio-fuel influences its behaviour during combustion (Demirbas, 2002) and thus, affects physical properties and quality of solid bio-fuel produced. It has been reported that when moisture content of a charcoal material stands at 18% and below, the charcoal material does not contain free water but rather bound water that is chemically combined with the environment of the charcoal material (Onchieku *et al*., 2012). This indicates that so long as a charcoal material contains moisture content of less than 18%, the bulk of its physico-chemical properties would not be influenced by moisture content. Consequently, as the moisture contents of all the wood-charcoal tested are quite below 18%, the materials contained no free water and therefore, the moisture content has no effect on the combustion and fuel properties of the wood-charcoals.

The wood-charcoals investigated in this study exhibited distinct ranges of ash content. The charcoal materials of *Anogeissus leiocarpus* (Marke) and *Ficus platyphylla* (Ganji) had ash content values of 6.51% and 5.35%, respectively. However, *Combretum lamprocarpum* (Zindi), *Butyrosperum paradoxum* (Tabo) and *Pakia biglobosa* (Dorawa) exhibited much higher ash content than the other two wood-charcoals, of which their values are 10.11%, 12.61% and 16. 91%, respectively. The high content of ash found in these charcoal materials may be attributed to the high accumulation of inorganic mineral such as calcium in their parent biomass (Kloss *et al*., 2012). Thus, wood-charcoal that is calcite-rich is bound to contain high ash content, as calcium is essential in the production of a good volume of ash and that large amounts of it injure combustion process (Yang *et al*., 2005). The wide range of ash contents displayed by these wood-charcoals materials provides options for selecting appropriately a wood-charcoal with desirable combustion and fuel properties for sustainable production and utilisation. For example, wood-charcoal with high ash content tends to consume more of solid bio-fuel for cooking than wood-charcoal with low ash content (Fig. 1). As such, percentage of ash content is one of the factors that affect specific solid bio-fuel consumption negatively. In addition, ash is a non-combustible component of wood-charcoal and thus, influences negatively on the heat transfer to the surface of a wood-charcoal as well as diffusion of oxygen to the solid fuel surface during charcoal combustion (Kim *et al*., 2001). This indicates that ash is an impurity that does not burn which in turn affects combustion volume and efficiency and as a result, wood-charcoals with low ash content are better well-matched for high fuel value and efficient thermal utilisation than wood-charcoals with high ash content (Table 2). This means that the higher the wood-charcoal's ash content, the lower its calorific value, which is consistent with the other studies reported in the literature (Kloss *et al*., 2012; Mitchell *et al*., 2013).

The charcoal materials of *Ficus platyphylla* (Ganji) and *Anogeissus leiocarpus* (Marke) were found to have low volatile matter content of 13.59% and 17.79%, respectively. The charcoals of *Combretum lamprocarpum* (Zindi), *Butyrosperum paradoxum* (Tabo) and *Pakia biglobosa* (Dorawa) were observed to have higher volatile matter of 26.59%, 31.35% and 34.59%, respectively, which suggest that these charcoal materials contained large amounts of substrates that support quick ignition and easy combustion, as well as provide high fuel value. This makes the wood-charcoals highly reactive fuels gave faster burning rate during combustion than the other two wood-charcoals influenced by low volatile matter. It has been reported in the literature that this feature determines stability of flame and combustion velocity, as volatile matters promote an increase permeability of flame in solid bio-fuels and reactivity of charcoal (Soares, 2011). However, high concentration volatile matter reduces productivity of wood-charcoal during cooking, as it quickens loss of wood-charcoal mass induced by thermal degradation. Therefore, wood-charcoal with low volatile matter content is better suited for domestic use, as it burns less vigorously than charcoal with high volatile matter. In addition, wood-charcoal with low volatile matter though difficult to ignite but burns very sluggishly and cleanly (Maes and Verbist, 2012), which is an advantage over others with high concentration of volatile matter that ignite easily and burn vigorously with smoke flame that is environmentally undesirable. The observed burning profile of the wood-charcoals depicted in Fig. 1 showed that the charcoal materials of *Ficus platyphylla* (Ganji) and *Anogeissus leiocarpus* (Marke) took the longest time of burning with less stress of loss of mass compared to other three bio-energy sources. This could also be adduced to their low percentage of volatile matter content. On the other hand, high concentration of volatile matter content indicates that during combustion, bulk of the mass of the charcoal materials of *Combretum lamprocarpum* (Zindi), *Butyrosperum paradoxum* (Tabo) and *Pakia biglobosa* (Dorawa) suddenly reduced due to quick volatility and burning of the bio-fuels.

The state's most commonly used wood-charcoals exhibited different range of fixed carbon composition, which considered to be the dominant component of the proximate analysis of the wood-charcoal materials. The wood-charcoal of *Ficus platyphylla* (Ganji) revealed the highest fixed carbon content value of 76.89%, followed by *Anogeissus leiocarpus* (Marke) with the percentage of fixed carbon of 71.10%. However, the charcoal materials of *Combretum lamprocarpum* (Zindi), *Butyrosperum paradoxum* (Tabo) and *Pakia biglobosa* (Dorawa) had the lowest percentage of fixed carbon contents, which were determined to be 26.59%, 31.35%, and 34.59%, respectively, possibly due to high volatile matter and ash contents. This observation is strongly supported by negative correlation between fixed carbon and volatile matter contents, as well as fixed carbon and ash contents ($R^2 = 0.9973$ and 0.9542, respectively; Fig. 2). Fixed carbon content of solid bio-fuel is considered to be the percentage of carbon available for the fuel combustion after volatile matter distilled off and therefore, roughly estimates the heating value of a solid bio-fuel (Nguyen, 2010), as carbon acts as the main generator of heat during combustion. Therefore, with higher fixed carbon content and relatively low ash content, *Ficus platyphylla* (Ganji) and *Anogeissus leiocarpus* (Marke) are best suited for thermochemical energy conversion processes. This can further be supported by the fact that wood-charcoal material with very low fixed carbon content tends to prolong cooking time by its low heat release and *vice versa* (Adegoke and Lawal, 1997). This fact alone suggests that fixed carbon content is the prime factor that dictates its caloric energy content of a solid bio-fuel, as high calorific energy usually corresponds with high fixed carbon content (FAO, 1995), Even though this is contrary to the observed results of *Butyrosperum paradoxum* and *Pakia biglobosa* (Table 1). This anomaly may be related to proportion of fixed carbon in the woods, which might be controlled *via* temperature and its resident time during carbonisation process. This could be supported by the plots depicted in Fig. 2, as it also infers that fixed carbon content increases with decrease in charcoal yield.

C, H, O, N, S and Cl analysis

The percentage of C, H, O, N, S, and Cl by weight and molar H/C and O/C ratios for the examined wood-charcoals samples are presented in Table 1 and 3, respectively. Carbon remained the dominant element in all the wood-charcoal samples. For all the five wood-charcoals were found to have almost similar carbon concentrations in the range between 70.26% and 76.59% except for *Pakia biglobosa* (Dorawa) that its carbon concentration was found to be the least in all the samples (64.38%). These wood-charcoal materials also had oxygen concentrations as the second highest elements that made up between 10.25% and 18.90%, followed by hydrogen concentrations that varied between 2.63% and 4.08% amongst the major compositional constituents of the wood-charcoals. This further suggests that the wood-charcoals have similar compositional structures and the concentrations of these major compositional constituents are in agreement with the earlier findings (Enders *et al*., 2012; Hammes *et al*., 2006). The H/C ratios for the wood-charcoals varied from 0.45 to 0.64, which fall within the range defined as black carbon (Graetz and Skjemstad, 2003). Similarly, O/C ratios ranged from 0.11 to 0.19, of which *Anogeissus leiocarpus* (Marke) had the highest O/C value suggesting a greater degree of oxygenated structure in this wood-charcoal. Therefore, the most commonly used wood-charcoals probably had condensed aromatic structures with certain degree of stability relative to their corresponding parent feedstocks.

Al, Ca, K, and Si analysis

As shown in Table 1, out of a total of about 28 elements detected in the wood-charcoal samples using EDXRF analysis, the relevant elements with high weight percentages are Al, Ca, K, and Si. The partitioning of such inorganic components in biomass can vary substantially depending on the biomass type. For example, the types of wood used in this study- *Anogeissus leiocarpus* (Marke), *Butyrosperum paradoxum* (Tabo), *Combretum lamprocarpum* (Zindi), *Ficus platyphylla* (Ganji), and *Pakia biglobosa* (Dorawa) are typically composed of Ca weight percentages of 8.21%, 28.05%, 17.09%, 15.92%, and 30.96%, respectively. On the other hand, *Ficus platyphylla* (Ganji) and *Anogeissus leiocarpus* (Marke) are both high in Al, K and Si weight percentages relative to other wood-charcoals. During combustion, K can typically react with other inorganic elements present in the ash formation to form reaction products such as K_2CaSiO_4 and/or $KAlSi_3O_8$ (Vassilev *et al*., 2014). Indeed, silicates have been indicated to facilitate fixation of potassium in wood-charcoal as potassium silicates (Vassilev *et al*., 2014). This formation of potassium species through either of chemical adsorption or physical adsorption in the charcoal matrix increases ash melting temperatures or prevents ash sintering during combustion process (Wang *et al*., 2012). Thus, potassium species exert favourable influence on burning qualities of biomass-based charcoals, as it greatly enhances the fire-holding capacity of a solid bio-fuel by lessening ash deposit. This could be reasoned that presence of abundant availability of aluminosilicate-based product ($Al_xSi_yO_z$) in the matrix of biomass-based charcoal makes it to acquire glassy property, which could be responsible for making the charcoal to have good fire-holding capacity. Stimulatingly, *Ficus platyphylla* (Ganji) and *Anogeissus leiocarpus* (Marke) showed such glassy features in accordance to both contained high Al, K and Si weight percentages (Fig. 3a and b showing only the spectra of the charcoals of *Ficus platyphylla* and *Anogeissus leiocarpus*, respectively) relative to other wood-charcoals. This evidently account for and further support the circumstance that revealed their sluggish burning characteristics (Fig. 1) compared to other examined wood-charcoals, since aluminosilicate-based materials hold capacity to withstand high temperature conditions because of their temperature resilient characteristics.

Respondents' perception on commonly used wood-charcoal species

The users' perception on the commonly used wood-charcoal species in Bauchi Metropolis is shown in Table 2. As the Cronbarch's Alpha results of the pilot survey and actual survey found to be 0.93 and 0.89, respectively, the result of the entire survey deemed as reliable and reflects the true users' perception in response to the combustion and fuelling characteristics of the commonly used wood-charcoal in the study area. The users' response reveals the characteristics of each of the wood-charcoal specie based on performance impression that the users perceptibly held with. The quality of the sampled wood-charcoals was adjudged on the basis of their physical condition where 91 and 89% of the respondents revealed that the structure of the cross section of charcoals of *Anogeissus leiocarpus* (*Marke*) and *Ficus platyphylla* (*Ganji*), respectively are compacted. This is contrary to the observation made in response to compactivity of charcoals of *Pakia biglobosa* (*Dorawa*), *Butyrosperum paradoxum* (*Tabo*), and *Combretum lamprocarpum* (*Zindi*) where majority of the respondents are on the opinion that these wood-charcoal species are deemed to be not compacted. Therefore, respondents vested their interest much on the charcoals of *Anogeissus leiocarpus* (*Marke*) and *Ficus platyphylla* (*Ganji*) due to their hardness- a property that turn them into marketable commodities with high demand from both retailers and final consumers. This is because compactness is perceived by the respondents that is an advantage that provides sufficient toughness to withstand exposure and shock of transportation and storage, as well as sluggishness in burning rate.

Table 2. Contextual observation of users' perception on wood-charcoals used in Bauchi Metropolis.

Names of wood-charcoal species	**Parameters' Response (%)**																
	Solidity (compactness)		**Ease of ignition**		**Heat output intensity**			**Rate of devolatisation**			**Burning Time**		**Ash Generation**		**Smoke**	
	Yes	No	Easy	Difficult	High	Medium	Low	Fast	Medium	Slow	Long	Short	Much	Low	Yes	No
Anogeissus leiocarpus (Marke)	91	9	13	87	82	14	4	3	9	88	96	4	0	100	95	5
Butyrosperum paradoxum (Tabo)	32	68	69	31	12	54	34	20	75	5	26	74	69	31	6	94
Combretum lamprocarpum (Zindi)	24	76	78	22	27	61	12	13	87	0	32	68	75	25	9	91
Ficus platyphylla (Ganji)	89	11	26	74	93	7	0	0	9	91	100	0	0	100	100	0
Pakia biglobosa (Dorawa)	0	100	97	3	12	57	31	91	9	0	7	93	100	0	2	98

On the ease of ignition, 97% of the respondents indicated that charcoal of *Pakia biglobosa* (*Dorawa*) catches fire easily, followed by the charcoal samples of *Combretum lamprocarpum* (*Zindi*) and *Butyrosperum paradoxum* (*Tabo*) with response of 78 and 69%, respectively. The charcoal samples of *Anogeissus leiocarpus* (*Marke*) and *Ficus platyphylla* (*Ganji*) were labelled with uneasiness to catch fire, as weighty proportion (87 and 74%, respectively) of the targeted respondents are on the opinion that these charcoals ignite with difficulty. This observation could be connected to compactivity orientation and a factor of volatile matter contents of all the charcoals, since charcoal's sponginess enables oxygen infiltration that support quick combustion in presence of plentiful volatile matter content in the charcoal matrix (Adegoke and Lawal, 1997; Vongsaysanaand and Achara, 2009).

The heat outputs from the charcoals of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) received greater respondents 'attention relative to other charcoal species. From the reached charcoal users, 93 and 82% of respondents perceived that the heat outputs dissipate by charcoals of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*), respectively are quite high compared to other charcoal species. On the other hand, these charcoal species were recorded with very low response on their rate of devolatilisation, 91 and 88% responded on the charcoals of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*), respectively that though the charcoals have high heat output, but burned slowly. The responses imply that these charcoals ignite not easily and burn with high intensity for a long time. Accordingly, it is such combustion and fuelling characteristics that have made the users in the study areas much prefer to use these charcoal species than any other charcoal species. However, 91% responded that the rate of devolatilization of charcoal of *Pakia biglobosa* (*Dorawa*) is fast while for those of charcoals of *Combretum lamprocarpum* (*Zindi*) and *Butyrosperum paradoxum* (*Tabo*) are moderate perceivably. This observation indicates that the combustion pattern of these charcoals is characterised by fast and/or moderate rate of devolatilization that matched with short burning time (Table 2). The user perception survey conducted demonstrated that in terms of acceptability, there is no market and household acceptability and preference for these charcoal species, particularly the charcoal of *Pakia biglobosa* (*Dorawa*). Although any hard savannah tree could be carbonised for charcoal, but the two-species of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) are mostly sought after and give preference in the study areas, which is attributed their hardness that makes their charcoal non-bristling with excellent fire-holding capacity.

For the case of ash generation, all the respondents indicated that the charcoals of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) burn with low ash generation. This could be attributed to their chemical composition since the charcoals appeared glassy due to high content of potassium, aluminium and silicon in their matrix and thus, make their charcoals prevent ash sintering and support fire-holding capacity. Conversely, respondents settled that charcoals of *Pakia biglobosa* (*Dorawa*), *Combretum lamprocarpum* (*Zindi*) and *Butyrosperum paradoxum* (*Tabo*) generate much ash during combustion process, which could also be linked to their nature of chemical composition (Table 1). Despite this disadvantage, these charcoals burn without smoke which was impressively supported by more than 90% respondents' perception (Table 2). This indicates that the charcoals of *Pakia biglobosa* (*Dorawa*), *Butyrosperum paradoxum* (*Tabo*), and *Combretum lamprocarpum* (*Zindi*) could improve final user's health by providing a cleaner burning fuel (although their burning time do not last long), as well as help to protect the environment by emitting little or no hazardous gases.

Conclusions

The findings of this study have shown that the most commonly wood-charcoals produced and utilise in the study areas have varied physico-chemical characteristics and have different acceptability potential. The physico chemical characteristics of the wood-charcoals assessed in this study showed that charcoals manufactured from *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) had low moisture contents (4.17, 4.60%, respectively) high calorific value (33.58, 30.09 MJ/kg, respectively) and low ash content (5.35, 6.51%, respectively). There is also an indication that the charcoals of these species have good fire-holding capacity due to their glassy index evident by high aluminium, potassium, and silicon contents observed. The survey has also revealed that the charcoals produced from *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*) are in high demand and received greater acceptability than the charcoals of *Pakia biglobosa* (*Dorawa*), *Butyrosperum paradoxum* (*Tabo*), and *Combretum lamprocarpum* (*Zindi*), which is attribute to their solidity, high-quality combustion outputs and durability during combustion process. Although the charcoals of *Pakia biglobosa* (*Dorawa*), *Butyrosperum paradoxum* (*Tabo*), and *Combretum lamprocarpum* (*Zindi*) can provide cleaner energy sources that could significantly cut pollutant emissions, and at the same time bring huge environmental quality and health benefits, but the final consumer give no preference to such characteristics rather the users perceptibly work on the charcoal performance that impress them. Therefore, the charcoals of *Ficus platyphylla* (*Ganji*) and *Anogeissus leiocarpus* (*Marke*), are the most chosen bio-solid fuels in the study area deemed suitable for both domestic and artisanal energy production for heat generation.

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REFERENCES

Adegoke, C. O. Lawal, G. T. (1997). Preliminary Investigation of Sawdust as High Grade Solid Fuel. Journal of Renewal Energy, 1- 2: 102-107.

AFREA/World Bank. (2011). Wood-Based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches.

Bauchi State Ministry of Land and Survey. (2015). Geographical Location of Bauchi.

Diarmaid, S. C. Patrick E. M. Christopher, M. R. Jenny, M. J. (2018). The effects of an additive on the release of potassium in biomass combustion. Fuel, 214: 647-655.

Demirbas, A. (2002). Relationships between Heating Value and Lignin, Moisture, Ash and Extractive Contents of Biomass Fuels. Energy Exploration and Exploitation, 20: 105–111.

Elsayed, Y. Dalibalta, S. Abu-Farha, N. (2016). Chemical Analysis and Potential Health Risks of Hookah Charcoal. Science of the Total Environment, 569–570: 262–268.

Elsayed, Y., Dalibalta, S., Gomes, I., Fernandes, N., Alqtaishat, F. (2014). Chemical Composition and Potential Health Risks of Raw Arabian Incense (Bakhour). Journal of Saudi Chemical Society, 11: 21-29.

Ekouevi, K and Tuntivate V. (2011). Household Energy Access for Cooking and Heating: lessons learned and the way forward. Washington (DC): World Bank; http: //dx.doi.org/10.1596/978-0-8213-9604-9. Retrieved on the 11/04/2018.

Enders, A. Hanley, K. Whitman, T. Joseph, S. Lehmann, J., 2012. Characterization of Bio-chars to Evaluate Recalcitrance and Agronomic Performance. Bio-resource Technology, 114: 644–653.

Enwerem, C.K. (2006). The Geology of Area around Miri, Bauchi N-E sheet 149. Unpublished thesis at the geology Department, Faculty of Science, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

FAO (1995): Industrial Charcoal Making. FAO Forestry Paper No. 63. Mechanical Wood Products Branch. Forest Industries Division. FAO Forestry Department.

Graetz, R. D. and Skjemstad, J. O. (2003). The Charcoal Sink of Biomass Burning on the Australian Continent.CSIRO Atmospheric Research, 64: 1–61.

Hammes, K. Smernik, R. J. Skjemstad, J. O. Herzog, A. Vogt, U. F. Schmidt, M. W. I. (2006). Synthesis and Characterisation of Laboratory-charred Grass Straw (Oryza saliva and Chestnut wood (Castanea sativa) as Reference Materials for Black Carbon Quantification. Organic Geochemistry, 37: 1629–1633.

Kim, H. J. Lu, G. Q. Naruse, I. Yuan, J. Ohtake, K. (2001). Modelling Combustion Characteristics of Bio-coal Briquettes. Journal of Energy Resource and Technology, 123: 27–31.

Kloss, S. Zehetner, F. Dellantonio, A. Hamid, R., Ottner, F. Liedtke, V. Schwanninger, M. Gerzabek, M. H. Soja, G. (2012). Characterization of Slow Pyrolysis Biochars. Effects of Feedstocks and Pyrolysis Temperature on Biochar Properties. Journal of Environmental Quality, 41: 990–1000.

Maes, W. H. Verbist, B. (2012). Increasing the Sustainability of Household Cooking in Developing Countries: Policy Implications. Renewable and Sustainable Energy Review, 16: 4204–21.

Mitchell, P. J. Dalley, T. S. L. Helleur, R. J. (2013). Preliminary Laboratory Production and Characterization of Bio-chars from Lignocellulosic Municipal Waste. Journal of Analytical and Applied Pyrolysis, 99: 71–78.

Mugo, F. and Ong, C. (2006). Lessons from Eastern Africa's Unsustainable Charcoal Trade. World Agroforestry Centre, Nairobi, Kenya.

Nguyen, B. T. Lehmann, J. Hockaday, W. C. Joseph, S. Masiello, C. A. (2010). Temperature Sensitivity of Black Carbon Decomposition and Oxidation. Environmental Science and Technology, 44: 3324–3331.

Onchieku, J. M. Chikamai, B. M. Rao, M. S. (2012). Optimum Parameters for the Formulation of Charcoal Briquettes Using Bagasse and Clay as Binder. European Journal of Sustainable Development, 1(3): 477–492.

Rabier, F. Temmerman, M. Bohm, T. Hartmann, H. Rathbauer, J. Fernandez, M. (2006). Particle Density Determination of Pellets and Charcoal. Journal of Biomass and Bioenergy, 30: 954– 963.

Soares, V. C. (2011). Thermal, Chemical and Physical Behaviour of Wood and Charcoal from Eucalyptus Grandisx Eucalyptus Urophyllaat Different Ages, PhD thesis on Wood Technology, Federal University of Lavras, Lavras, Brazil.

Sotannde, O. A. Oluyege, A. O. Abah, G. B. (2010). Physical and Combustion Properties of Charcoal Briquettes from Neem Wood Residues. International Agrophysics, 24: 189-194.

UNDP (2009). The Energy Access in Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa. UNDP, New York, NY.

UNDP and WHO (2009). The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa. The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa, New York.

Van-Beukering, P. G. Kahyarara, E. Massey, S. di Prima, S. Hess, V. Makundi, K. van der Leeuw, A. (2007). Optimization of the Charcoal Chain in Tanzania. Poverty Reduction and Environment Management (PREM) Programme. Institute for Environmental Studies, Amsterdam, The Netherlands.

Vassilev, S. V. Baxter, D. Vassileva, C. G. (2014). An Overview of the Behaviour of Biomass During Combustion: part II. Ash Fusion and Ash Formation Mechanisms of Biomass Types. Fuel, 117: 152–83.

Vongsaysanaand, S. Achara, U. (2009). Comparison of the Physical and Chemical Properties of Briquette and Wood Charcoal in Khammouane Province, Lao PDR. Environment and Natural Resources Journal, 1(7): 1-13.

Wang, L. Hustad J. E. Skreiberg, Ø. Skjevrak G. Grønli, M. A. (2012). Critical Review on Additives to Reduce Ash Related Operation Problems in Biomass Combustion Applications. Energy Process, 20: 20–9.

Yang, Y. B. Ryu, C. Khor, A. Yates, N. E. Sharifi, V.N. Swithenbank, J. (2005). Effect of Fuel Properties on Biomass Combustion. Fuel, 84: 2116–2130.