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Research article

Agro-residues for clean electricity: A thermo-property characterization of cocoa and kolanut waste blends

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HIGHLIGHTS

- Cocoa and kolanut harvest wastes of 681,000 and 90,000 tons respectively, are generated in Nigeria annually.
- HHVs of the two agro-residues are 15.19 and 13.87 MJ/kg respectively, with their blends having values within this range.
- The optimal blend composition of the two agro-residues has electric power generation potential estimated at 29,000 MW.

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ABSTRACT

Huge quantities of harvest wastes that are generated from agricultural practices at every farming season in Nigeria are not put into significant use. As an attempt towards adopting these abundant by-products as bioenergy resources for electricity generation, yearly quantities of both cocoa and kolanut harvest residues were estimated in this study. Hygroscopic natures and moisture contents of the two, and their blends, were also analyzed and compared. It was estimated that approximately 681,000 tons and 90,000 tons of cocoa and kolanut husks respectively, are produced in the country annually. While the proximate analyses showed that the sample made of 100% cocoa waste had the least volatile matter and moisture contents in addition to having highest fixed ash and fixed carbon contents, the reverse was the case with the sample made of 100% kolanut waste composition. From the ultimate analyses, however, the latter appears to possess the best characteristic (highest hydrogen and least oxygen contents), but its highest nitrogen content is a pointer to its exhibition of poor thermal property. The gross calorific contents of the samples were, therefore employed for definitive determination of their thermoelectric potentials and these gave higher heating values of 15.19 MJ/kg and 13.87 MJ/kg respectively, with the blends having their values within this range in proportionality to the mass percentage of kolanut husk in the blends. In addition to the two wastes exhibiting good energy characteristics, the study concludes that their blending offers benefit of reduction in ash content. At the optimal blend of equal composition of the two materials (50%CPH/50% KPH), it was estimated that 29,000 MW of electricity is accruable from the wastes.

1. Introduction

Secure and adequate provision of modern energy services, in the forms of clean electricity and cooking fuels, are generally considered pivotal to national development. A glance through the electrification map of Nigeria shows a sub-Saharan African nation that is in significant need of affordable and reliable electric power supply [1]. With only 55.4% of its total population having access to electricity currently, Nigeria faces critical questions about engineering its economic development particularly as related to electric power supply [2]. However, a vantage position is that the country could sustainably harness renewable energies to cater for the electricity need of its un-served and under-served population since the nation is enormously endowed with renewable energy resources in the forms of small-hydro, wind, solar, and natural biomass.

For electric power generation, a promising alternative to the use of conventional fuels has been found in renewable energy technology. Off-

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grid electrification using electricity generated from non-conventional energy resources, together with installation of stand-alone distribution minigrids, has been adjudged capable of securely delivering electricity for lighting, water supply, telecommunication, irrigation and small-scale commercial purposes, among others [3, 4, 5]. The negative impacts of carbon footprints of fossil fuels on the environment and the possibility of depleting the natural reserve of fossils, are other reasons for Nigeria to tilt towards the clean and replenishable alternative resources for the development of its energy sector [6, 7, 8].

Owing to their renewable nature, agricultural waste products constitute a class of biomass that are being used to produce utility-size electricity in many parts of the world. As an agrarian nation, production of export crops is a popular agricultural practice in Nigeria that yields enormous quantities of harvest wastes, most of which are not put into efficient utilization. Cocoa (*Theobroma Cacao*) is the most prominent of all the major cash crops in South-West Nigeria. For several decades, the nation has been globally ranked with the leading producers of cocoa with yearly production estimated by [9] as 350,000 tons. Another export crop that is prominently produced in the region is kolanut (*Cola*) and according to [10], not less than 70% of the world's annual production of kolanut currently comes from Nigeria. Over 200,000 tons of the nut is produced in the country yearly according to [11, 12]. It is submitted in [13] that average production of the two crops over five years (2015–2019) are 323,000 tons and 162,500 tons respectively. *Criollo*, *Forastero* and *Trinitario* are the three species of cocoa that are popularly grown in Nigeria, while the two species of kolanut that are of economic importance in the country are *Cola-Acuminata* and *Cola-Nitida*. Fruit pods are the main harvest wastes of these two crops, which though abundantly available during harvest seasons, yet have not been considered for serious commercial or industrial utilization. Nigeria can therefore jump over its backlog in electric power need by exploring and exploiting these agro-residues as bioenergy resources for electrification.

Amidst the rising global demand for electricity, biomass has become viable energy resource option for power generation. Lowness in cost and emission, abundant availability and easy accessibility make biomass suitable for providing reliable electricity supply to remote isolated areas. Presented in [14] was an investigation on electric power generation at some primitive palm oil mills in North Sumatera using palm oil processing residues. Interviews, questionnaires and data collection were used to analyse some mills for their potentials to generate electricity from waste materials like FFB, PNS and PNF. Electric power ranging from 20MW to 35 MW was generated by a mill that operated at 30 tons FFB per hour, as obtained from the results of the study. Authors in [15] assessed how generation of electric power from the wastes of the winter cereals grown in certain farming area in Spain could be sustained. As a case study, straw biomass from three distinct annual winter cereals were used to energize a biofuel power plant of 25MW generation capacity. Comparison was thereafter made between the results obtained from the analyses and the performances of the fuel- (natural gas) fired Spanish power plants. It was found that the GHG emission due to the combustion of the winter cereals biomass was considerably lower than what was obtained when natural gas was the fuel. The use of pine sawdust in the steam explosion process of energy production has been modelled for suitability [16]. The modelling revealed 533–590 K temperature and 4.7–10.8 MPa pressure as the operating conditions that are suitable for the process of removing moisture and hemicellulose from pine dust in order to improve energy production by the pine biomass. Ref. [17] introduced a novel biomass-fired cooking stove that used a thermoelectric module to generate electricity that powered fan and gave light. It was first developed in a laboratory, after which a prototype was constructed. The design of the laboratory-scale prototype is detailed in [18], while [19] in giving the results obtained from the subsequent field testing of the device in Malawi, showed that a rechargeable lithium iron-phosphate ($LiFePO_4$) battery or any 5V appliance could be charged using the energy produced by the stove-based electricity generator. Another technique for exploiting biomass energy was presented in [20] as gasification process, which was compared with other methods. Though not fully developed like other technology, the study found biomass gasification to have advantages of higher operational efficiency and reduction in CO_2 emission. Ref. [21] itemized the major factors that must be put into consideration in designing gasification plants, in the effort to boost the level of implementation of the technique.

Property characterization is an important requirement in processing biomass for electricity generation [22]. Due to the hygroscopic nature and the moisture content of most agro-residues, the type of pre-treatment required to upgrade the fuel quality and the shelf-lives of the materials must be investigated before they could be confidently deployed. Fresh cocoa pod has been characterized in [23], wherein the waste product has been adjudged as having high energy content. Physic-ochemical properties of common lignocellulosic agricultural residues that are available in India was characterized in [24]. The study found corn-cob to have 61.2% content of cellulose and hemicellulose, making it the highest; while cotton stalk has relatively higher thermo-chemical potential due to its HHV of 19.2 MJ/kg. The most significant properties of particles during fuel combustion are volatile matter and fixed carbon contents [25]. Biomass materials are enabled for use as energy resources by these two properties because the measure of the ease with which biomass fuels can ignite and subsequently oxidize or gasify is significantly provided by the two factors [26, 27, 28]. On the other hand, ash deposition and corrosion are two major technical challenges to efficient utilization of biomass for electric power (or heat) generation. The ash produced by biomass contained high level of alkali metals, particularly sodium. It also contains chlorine and sulphur in minute concentration that causes the deposited ash to become corrosive in a way that is more severe than that of coal [29, 30, 31]. It is reported in [32] that as a result of slagging and fouling, there is always a high rate of decomposition in most of the boilers where biomass is used as fuel. In situations where chlorine is present, this problem escalates as alkali chloride is formed. Authors in [33] examined some sawdust of wood species in Nigeria for gross calorific contents and the result of the examination showed 13 of the sawdust species as having values ranging from 20 MJ/kg to 26 MJ/kg. Reported in [34] is a comparative investigation of elemental contents of the Nigerian sawdust species and some species of coal that are found in the literature. With the measuring of carbon, hydrogen, sulphur, nitrogen and oxygen contents, the result of the comparison revealed that unlike coal, the use of sawdust as energy feedstock has minimal or no negative environmental effect.

Blending of different agro-residues has been considered as a subtle way of improving energy characteristics of the materials. A blend of olive waste and sawdust was produced in [35] with the physico-chemical properties of the product agro-pellets determined. The result showed improvement in the moisture content of the olive waste. In [36], sawdust of three Nigerian local woods: *Iyeye* (*Spondias Mombin*), *Afara* (*Terminalia Superba*) and *Iroko* (*Chlorophora Excelsa*), alongside with a blend of the three; were sampled and thermally characterized in detail. While the study ascribed the leading thermo-electric potential to *Afara* because it exhibited the least moisture content, very low ash content and the highest volatile matter; it was revealed by ultimate analyses that the blend, with its highest hydrogen and oxygen contents, had the best heating characteristic. A technique for reducing the cost of feedstock without trading off the bulk density of bioresources was presented in [37]. Blending and densification of feedstocks were demonstrated as means of addressing the supply chain challenges. The high costs of reliance on a single feedstock resource was reduced as the blending takes advantage of low-cost feedstock, while increase in bulk density and inculcation of desirable feed handling properties were achieved through the densification process. The blending approach used in [38] focused on mitigating the formation of slag, as well as minimizing the emission levels of both particulate and gaseous matters. Raw materials that have critical fuel composition were blended with less problematic biomasses, and a small scale combustion appliance with a nominal heat capacity of 30kW was employed to experiment the combustion using three pellets of pure (pine wood, miscanthus and wheat straw) and seven pellets of blended biomasses. The study showed that during combustion of herbaceous fuels, significant reduction in slagging risk was only achieved for high blending ratios with more than 70wt% wood. In [39], various blends of switch-grass and pine wastes, with varying physical and chemical properties, were evaluated. The measured properties are density, compressibility, flow-ability and particle size distribution. Compositional and elemental analyses were also carried out on the materials.

The current study aimed at estimating the yearly quantities of two of the common agro-practice wastes (cocoa and kolanut pods) that are available in Nigerian. The characterization of their thermal properties to determine their suitability for adoption as bio-energy feedstocks for electric power generating plants was also investigated. Samples of varying proportions of the mixture of the two wastes were prepared with their hygroscopic natures and moisture contents investigated using standard procedures for proximate and ultimate analyses. This was done to determine the type of pre-treatment that could be required to upgrade their fuel qualities and the shelf-lives of their husks (dried pods). GCV which is one of the most significant properties of fuels, by which the efficient use of biomass and fossil fuels is dictated, was also determine [40, 41, 42]. The choice of mixing the two waste products was informed by the fact that the two are generally intercropped, in addition to their abundant availability and coinciding harvest seasons. While there have been studies on thermo-characterization of cocoa pod [23], kolanut pod has not been so investigated. More so, the advantage that blending cocoa pod with another waste, such as kolanut pod, could offer needs to be evaluated. This study thus examined the thermo-properties of kolanut waste as a pure feedstock, in comparison with pure cocoa waste feedstock, and then a number of mass-proportion blends of the two wastes.

2. Materials and methods

Seasonal quantities of the two wastes were estimated to determine the actual availability. For the study, fruits of *Criollo* specie of cocoa and *Cola Nitida* specie of kolanut were obtained from a plantation farm in Isaobi-Ijesa in Atakunmosa-West area of Osun State, South-West Nigeria. Choice of the species was simply based on their commonness in the agricultural region. FCFP and FKFP obtained from the fruits were processed to dryness naturally. Mixtures of powdered CPH and KPH were thereafter produced at varying mass-proportions of the contents, with proximate, ultimate and calorific analyses of samples of the mixtures carried out according to some standard procedures.

2.1. Estimation of seasonal quantities of the wastes

About 1 ton of freshly harvested cocoa fruits was obtained from the local farms and made to pass through the traditional post-harvest processing procedure as shown in Figure 1 (a)–(d). Following separation of the beans from the pods, the beans were kept for 120 hours to ferment after which the two products (beans and pods) were separately processed to complete dryness through the natural method of open-air sun drying. The products were thereafter weighed separately to give the quantity of the husks (dried pods) corresponding to the known quantity of the dried beans. These values were then used to estimate the approximate yearly quantity of the husks from the yearly quantity of the dried beans obtained from the literature.

By procedures almost similar to the description of cocoa processing, about 0.25 ton of freshly harvested kolanut fruits obtained from the same locality was also processed, as shown in Figure 2 (a)–(d). The nuts were separated from the pods, following which the pods were sun dried naturally in the open air, while the nuts were kept under tarpaulin covering for 96 hours with occasional moistening to make the testa turn black and rotten away. The nuts were thereafter soaked in water for 20 hours, skinned, rinsed and allowed to drain-off of water before they were passed through a curing process which involved maintaining them under ambient temperature for a period of another 92 hours. The curing was followed by some form of packaging that involved enveloping the nuts with certain sort of raw leaves for a period of one month with weekly inspections. During the packaging, a considerable sweating took place that reduced the moisture content of the nuts. The two products (processed nuts and dried pods) were thereafter weighed separately and the weight of the husks (dried pods) was compared with that of the processed nuts. Based on the yearly quantity of processed nuts as available in the literature, the approximate yearly quantity of kolanut husks was therefore estimated.

Figure 1. Images showing the traditional post-harvest processing of cocoa products: (a) portion of the sampled cocoa fruits as freshly harvested, (b) separation of the beans from the pods, (c) sun-drying the beans, and (d) natural open-air drying of the pods.

Figure 2. Images showing the traditional post-harvest processing of kolanut products: (a) portion of the sampled kolanut fruits as freshly harvested, (b) separation of the beans from the pods, (c) processed nuts, and (d) natural open-air drying of the pods.

2.2. Characterization of the CPH/KPH blends

For thermo-property characterization of CPH and KPH, some quantities of the two wastes were dried using natural open-air drying approach over a period of 12 days and then stored in sealable polyethylene bag at 25 °C for 15 days before the analyses started, For the analyses, the dried wastes were separately milled into fine powders, with an average particle size of 1 mm, using a knife-mill with attached bottom screen. The two powders were thereafter mixed in the proportions listed in Table 1 to give nine blends in addition to two (Sample A and K) pure feedstocks. Bulk density of each sample was then determined in accordance with the CEN TS15103 method. The mass and the volume of each sample were determined by filling a weighed container of 600ml to its maximum capacity. This was achieved by first filling the container to a 30cm height above the container's rim, followed by dropping on a firm surface from a height of 15cm in order to permit pressing down and settling of the material. If there was any space created by the dropping, the container was filled up again by the same procedure and then the excess material was scrapped away across the rim.

Table 1. Blending of the CPH/KPH agro-waste biomass.

S/N	Nomenclature	Composition	
		% Weight CPH	% Weight KPH
1	Sample A	100	0
2	Sample B	90	10
3	Sample C	80	20
4	Sample D	70	30
5	Sample E	60	40
6	Sample F	50	50
7	Sample G	40	60
8	Sample H	30	70
9	Sample I	20	80
10	Sample J	10	90
11	Sample K	0	100

2.2.1. Proximate analysis

The American Standard Testing Method (ASTMD 3174-76) was adopted for the proximate analysis of the samples. The moisture and the dry matter contents of each sample were determined using Gallenkamp Drying Oven (Model: OPL150.TS1.B), while Gallenkamp Muffle Furnace (Model: FRH002.XX1.5) was employed for the determining of the ash and volatile matter contents. Fixed carbon matter content was derived from the values of other contents.

The determination of the moisture and the dry matter contents were achieved by measuring 2g of the sample into a crucible of mass m_1, which was then placed in the oven for steady dryness at a constant temperature of 105 °C, while the gradual changes in the mass were recorded at 6-hour intervals till attainment of a constant mass m_2 of the crucible with its final content. The ash content was determined by putting 2g of the blend in the crucible that was thereafter placed in a furnace maintained at 900 °C temperature for at least 6 h till a white greyish matter was obtained. The amount of the ash content was determined from mass m_3 of the crucible with its final content. In the case of the volatile mater content, this was determined by heating about 2g of the sample for 6 min in the furnace that was set at 600 °C temperature, the combine mass of crucible, lid and sample being m_4. This was followed by another 6 min of heating at a temperature of 900 °C and, the amount of volatile matter present in the sample was equal to weight loss.

$$\%\,Moisture\ Matter\ Content(MMC) = \frac{(M + m_1) - m_2}{M} \times 100 \tag{1}$$

Therefore, the % $Dry\ Matter\ Content = 100 - (\%MMC)$

$$\%\,Ash\ Matter\ Content(AMC) = \frac{m_3 - m_1}{M} \times 100 \tag{2}$$

$$\%\,Volatile\ Matter\ Content(VMC) = \frac{M - (m_4 - m_1)}{M} \times 100 \tag{3}$$

$$\%\,Fixed\ Carbon\ Content = 100 - (\%MMC + \%AMC + \%VMC) \tag{4}$$

where M is the mass of the sample.

2.2.2. Ultimate analysis

Through ultimate analysis, the compound in a material is partitioned into its chemical components depending on its chemical properties. The partitions include elemental fractions: carbon, hydrogen, oxygen, sulphur and nitrogen; as well as hydrogen/carbon and oxygen/carbon ratios.

A Leibig-Pregle Chamber containing magnesium percolate and NaOH was used to determine carbon and hydrogen contents of each sample. By burning off inside the chamber 2g of a blend measured into a platinum crucible, CO_2 and H_2O were produced and absorbed by NaOH and magnesium percolate respectively. The differences in magnesium percolate and the NaOH give the quantities Q_1 and Q_2 that were used to determine the CO_2 and the H_2O produced.

$$\%\ Carbon\ Content\ (CC) = \frac{Q_1 \times 0.2727}{M} \times 100 \tag{5}$$

$$\%\ Hydrogen\ Content\ (HC) = \frac{Q_1 \times 0.1117}{M} \times 100 \tag{6}$$

where M is the mass of the sample.

Determination of the percentage nitrogen contents of the samples was achieved using Kjeldahl method. In this approach, 0.5g of a sample was measured into a Kjeldahl Digestion Tube (Model: EW-35200-04) and a Kjeldahl catalyst tablet and 10ml of concentrated H_2SO_4 acid was added. The tube with its content was then placed in a Digestion Block Heater (Model: EW-36630-00) in a fume cupboard for 4 hours, resulting in the formation of a clear colourless solution. This digest was then cooled and transferred into 100ml volumetric flask and the flask was made up to mark with distilled water. The digest was thereafter distilled using Markham Distillation Apparatus (Model: MC46/SC) as 5ml of it was pipetted into the apparatus and 5ml of 40% NaOH solution added. For 2 minutes, the mixture was steam-distilled into a conical flask containing 10ml of 2% boric acid and mixed indicator solution. Colour change from red to green, of the acid-indicator solution, showed that the liberated ammonia has been trapped and so the green colour solution was then titrated against 0.01N HCl. The colour turning from green to wine at the end point, indicated that all the nitrogen trapped as $(NH_4)_2BO_3$ has been removed as NH_4Cl, and the percentage nitrogen of the sample was thus determined while the difference gave the sample's percentage oxygen content.

$$\%\ Nitrogen\ Content\ (NC) = TV \times M_N \times N_{HCl} \times 4 \tag{7}$$

where:

TV is the titre value.
M_N is the atomic mass of nitrogen.
N_{HCl} is the normalcy of the HCl used.

2.2.3. Determination of the gross energy contents

Gross energy contents of the samples were determined through the method of comparison employed in ballistic bomb calorimeter. The calorimeter (Model: 5E-AC/PL) compares the energy content of a material with that of a known quantity of benzoic acid. A measure of the sample (0.25g) was weighed into the steel capsule of the bomb and a 10cm cotton thread attached to the bomb. A thermocouple-galvanometer system measures the maximum temperature rise in the bomb. Closed and charged-in with oxygen up to 30 atm, the bomb was then fixed up by depressing the ignite switch to burn the sample in an excess of oxygen. The temperature increase of the bomb was then compared with the value obtained for the 0.25g of benzoic acid. This was repeated 5 times for standardizing, with the average value computed as the calorimetric constant that was employed to determine the calorific value of the sample by a stepwise calculation.

$$\mathfrak{h} = \frac{(T_1 - T_2)\gamma}{M} \tag{8}$$

and

$$\gamma = \frac{(\mathfrak{h}_1 - M_B)}{(T_3 - T_2)} \tag{9}$$

where:

$\mathfrak{h}$ is the calorific value of the sample in kcal/g
γ is the calorific constant
$\mathfrak{h}_1$ is the calorific value of 1g of benzoic acid, which equals 6.32 kcal/g
T_1 is the galvanometer deflection with sample
T_2 is the galvanometer deflection without sample
$T_1 - T_2$ is the galvanometer deflection of sample
T_3 is the galvanometer deflection of benzoic acid
mass of the sample, M = mass of the benzoic acid, $M_B = 0.25$g

2.2.4. Electric power generation potential of the wastes

Different methods are used to convert biomass to electrical energy. Heat energy obtained from biomass materials can be used to produce steam to drive a turbine that is connected to electric power generator. On another way round, liquid or gaseous biofuel obtained from biomass can be used on ignition engine that is deployed to serve as prime-mover for electric power generator. An amount of energy that produces electric power supply or heat system for an hour is termed ERP, while PGP is the amount of energy that can produce electric power supply or heat system for 24 hours, and these are obtained as [43]:

$$ERP\ (kWh) = LHV \times W_t \times \frac{1000}{860} \times \beta \tag{10}$$

Where, ERP is the energy recovery potential of the biomass; LHV is the low heating value, which is obtained as $LHV = HHV - 9H \times LHS$ [44]; W_t is the weight of the biomass measured in tons; and β is a conversion efficiency with its value ranging between 22% and 28%; while LHS is the latent heat of steam. The PGP is obtained as [43]:

$$PGP\ (kWh) = \frac{ERP(kWh)}{24} = LHV \times W_t \times 0.04845 \times \beta \tag{11}$$

3. Results and discussion

On processing to complete dryness, the cocoa beans weighed 240 kg (0.24 ton) while the corresponding husk measured 506 kg (0.506 ton). With 323,000 tons average annual production of dried cocoa beans in Nigeria, the yearly production quantity of cocoa husks in the country is, therefore, estimated to be 681,000,000 kg (681,000 tons). In similar vein, the processed kolanut fruits yielded 103 kg (0.103 ton) of drained nuts with corresponding 57 kg (0.057 ton) of husks. Since the average annual production of kolanut in Nigeria is 162,500 tons of processed nuts, the yearly quantity of kolanut husk produced in the country is estimated to 90,000,000 kg (90,000 tons). This shows availability of the wastes at quantities that could sustain minigrid electrification in the rural areas of the Southwestern Nigeria.

The bulk densities of the samples are as described by Figure 3, which shows pure CPH (Sample A) as having the highest value, 712.6 kg/m^3, while the least is Sample K (pure KPH) with 703.8 kg/m^3. The blends have their bulk densities proportional to the percentage weight of KPH in the samples. This is obvious as CPH is having higher value than KPH. However, inquiry into this feature of the two wastes is necessary for hardness and durability, transportation and storage, as well as potential energy densification of the biomass [45].

Presented in Table 2 are the values obtained from the proximate and the ultimate analyses of the two waste materials. The MMC is 10.96% in Sample A and this is the lowest, while its highest value was from Sample K with 13.21%. There was an increase in the MMC of the blends, ranging

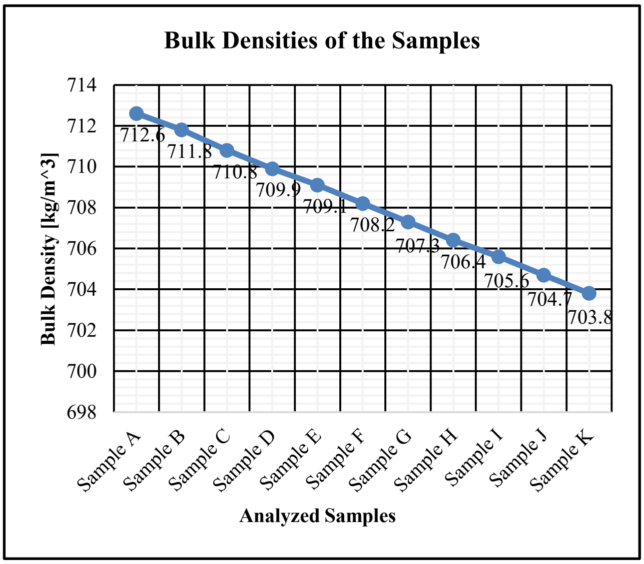

Figure 3. Bulk densities of the CPH/KPH samples.

from 11.19% to 12.99%, as the mass proportion of KPH in the blends increased. This same trend was exhibited by the samples as regards VMC, with the lowest and the highest values being 62.89% and 65.92% respectively, while the blends similarly have their VMC values ranging from 63.19% to 65.62%. The results obtained for FAC and FCC showed Sample A as having the highest values, 13.42% and 12.73% respectively, while lowest values were recorded from Sample K as 10.63% and 10.24% respectively. In the case of the blends, the values of the two contents reduced with increase in the mass proportion of KPH, ranging 13.14%–10.91% and 12.48%–10.49% respectively.

Generally, excessive ash content causes problems of corrosion and deposits formation in biomass-fired suspension boilers [24, 29, 30, 31] and blending of biomass materials or addition of additives to biomass have been practiced as means of alleviating these problems [46]. Therefore, the gradual reduction in the ash content of blends due to the increasing proportion of KPH, as obtained in this study, presents a benefit offered by blending the two agro-residues.

From the ultimate analyses, the elemental C, H, S, O and N components are linearly dependent on the mass of KPH in the samples. While C and O contents are inversely proportional, H, S, and N are directly proportion to proportion of KPH. H:C ratio increased from 0.087 (corresponding to Sample A) to 0.112 (corresponding to Sample K) with the blends having values of 0.089–0.110 range as the mass of KPH increased. Reverse was the case with O:C ratio as there is decrease from 0.975 (corresponding to Sample A) to 0.956 (corresponding to Sample K), with the blends having values of 0.0973 to 0.0956 range depending on the mass proportion of KPH in each.

The main combustible elemental component of biomass is C and this is followed by H, which has more calorific value than C, though [16, 47]. N does not support combustion; O reduces the energy content of biomass while S and N are associated with formation of SO_x and NO_x during combustion [16, 48, 49]. Increase in the energy indices of C and H lowers the calorific potential of O [47], and such lowering causes increase in calorific value of biomass [50]. Energy content of solid fuel is therefore generally related to the atomic hydrogen to carbon (H:C) and the atomic oxygen to carbon (O:C) ratios, with high H:C ratio corresponding to high energy content and high O:C ratio meaning low energy content. Thus the elemental ratios presented in Table 2 are also pointers to the improvement in the energy potentials of the blends as the proportion of KPH increases.

However, while the least MMC and VMC were from Sample A that, on one hand, has highest FAC and FCC, sharp reverse is the case with Sample K. The latter, of all the samples, appears to possess the best characteristic by having the highest hydrogen and lowest oxygen contents, but its highest nitrogen content is a pointer to its exhibition of poor thermal property since nitrogen does not support burning. GCV (HHV) is therefore employed for definitive determination of the thermoelectric potentials of the samples. As usually of biomass, HHV ranges from 11 MJ/kg to 35 MJ/kg [51, 52].

As revealed by Figure 4, Sample A has the highest HHV (15.91 MJ/kg), while that of Sample K is 13.87 MJ/kg and is the lowest. Each of the blends exhibits a value that is higher than the 11 MJ/kg minimum, ranging from 15.72 MJ/kg to 14.07 MJ/kg as the mass proportion of the KPH increases.

Notwithstanding the reductions in FAC as the mass proportion of KPH in the blends increases, HHVs reduces in direct proportionality to FAC. The charts presented as Figure 5(a)–(d) show the relationship between the calorific values and the ultimate analyses of the samples. In as much that the percentage composition of hydrogen increases while that of oxygen decreases proportionately with the increase in KPH as shown in Figure 5(a) and 5(b) respectively, then the reduction in the HHV, is attributable to the decreasing elemental carbon component and the corresponding increase in elemental nitrogen component, as revealed in Figure 5(c) and (d) respectively. The main components for combustion of biomass are carbon and hydrogen while nitrogen does not support combustion [16].

In general, the two waste materials, either blended or not, obviously exhibit good energy characteristics and, thus can find use as bio-energy feedstock in electric power generating plants. However, with the

Table 2. Proximate and ultimate analyses of sample CPH/KPH.

Sample	Proximate Analysis (% content)				Ultimate Analysis (% content)						
	MMC	VMC	FAC	FCC	C	H	S	O	N	H:C	O:C
A	10.96	62.89	13.42	12.73	47.48	04.14	0.573	46.29	01.52	0.087	0.975
B	11.19	63.19	13.14	12.48	47.42	04.25	0.576	46.14	01.61	0.089	0.973
C	11.41	63.50	12.86	12.23	47.36	04.36	0.582	45.99	01.69	0.092	0.971
D	11.64	63.80	12.58	11.98	47.30	04.47	0.588	45.85	01.78	0.095	0.969
E	11.86	64.11	12.30	11.73	47.24	04.58	0.594	45.70	01.87	0.097	0.967
F	12.09	64,41	12.03	11.49	47.17	04.70	0.600	45.55	01.96	0.100	0.966
G	12.32	64.71	11.75	11.24	47.11	04.81	0.606	45.40	02.04	0.102	0.964
H	12.54	65,01	11.47	10.96	47.05	04.92	0.612	45.25	02.13	0.105	0.962
I	12.76	65.31	11.19	10.74	46.99	05.03	0.618	45.10	02.22	0.107	0.960
J	12.99	65.62	10.91	10.49	46.93	05.14	0.624	44.96	02.30	0.110	0.958
K	13.21	65.92	10.63	10.24	46.87	05.25	0.630	44.81	02.39	0.112	0.956

Note: MMC = Moisture Matter Content, VMC = Volatile Matter Content, FAC = Fixed Ash Content, FCC = Fixed Carbon Content, C = Carbon, H = Hydrogen, S = Sulphur, O = Oxygen, N = Nitrogen, H:C = Hydrogen/Carbon Ratio, O:C = Oxygen/Carbon Ratio.

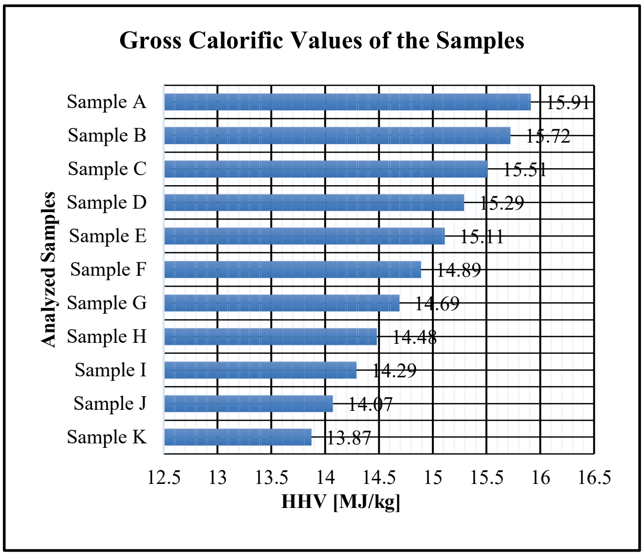

Figure 4. Gross calorific values of the CPH/KPH samples.

blending simultaneously offering merit of reduced FAC and demerit of corresponding reduction in HHV, finding a compromise between these two opposing features of the blending would further bring to fore the benefit of the two agro-residues. The average HHV of all the samples equals the HHV of Sample F that has 50%CPH/50%KPH composition. The sample could therefore be regarded as the optimal blend and thus used for estimating the electric power potential of the agro-wastes.

According to [53, 54], HHV is employed to adequately project; not only the thermal energy, but also the electrical energy potentials of biomass. It should be noted that Eqs. (10) and (11) assume a steam power plant. The *LHS* is 587 kcal/kg, where 1 MJ/kg = 238.8459 kcal/kg. By adopting the optimal blend ($HHV = 14.89\,MJ/kg$) and using the aggregate of the estimated quantity of the two wastes ($W_t = 681,000+90,000 = 771,000$ tons), projection of the electric power production from the wastes is obtained as:

$$HHV = 14.89\,MJ/kg = 3,556.42\,kcal/kg$$

$$LHV = 3,556.42 - (9 \times 0.0047) \times 587 = 3,531.59\,kcal\,/\,kg$$

$$PGP = 3,531.59 \times 771,000 \times 0.04845 \times 0.22 = 29,022,920.93\,kW = 29,000\,MW$$

4. Conclusion

Waste products from agricultural practices are always available in large quantities during harvest seasons in Nigeria. This study estimated yearly quantities of cocoa and kolanut husks to be approximately 681,000 tons and 90,000 tons respectively. From proximate and ultimate analyses, it is obtained that the elemental compositions of the two materials, and a number of their blends, are of the kinds that could support thermochemical or biochemical conversion of the materials to biofuel. Gross calorific contents of the optimal blend of the two agro-wastes is found to be 14.89 MJ/kg, while possible quantities of electric power accruable from the wastes is estimated to be 29,000 MW. It was also obtained from the study that the blending of the two materials could provide a means of reducing the ash contents. This investigation thus shows that owning to their availability in sustainable quantities, as well as their thermal properties, utilization of the two agro-residues as energy resources for microgrid-based electric power generation could be instigated.

With Nigeria requiring substantial investment in energy as the country is on the verge of embarking on its own developmental trajectory, energy resources for electric power generation need to be diversified. Thus depending on the economic and environmental context of the exact siting of electricity generating plants, these two agro-wastes could make good energy feedstock materials. Favourable political decision on adoption of biomass in general and agro-residues in particular as part of

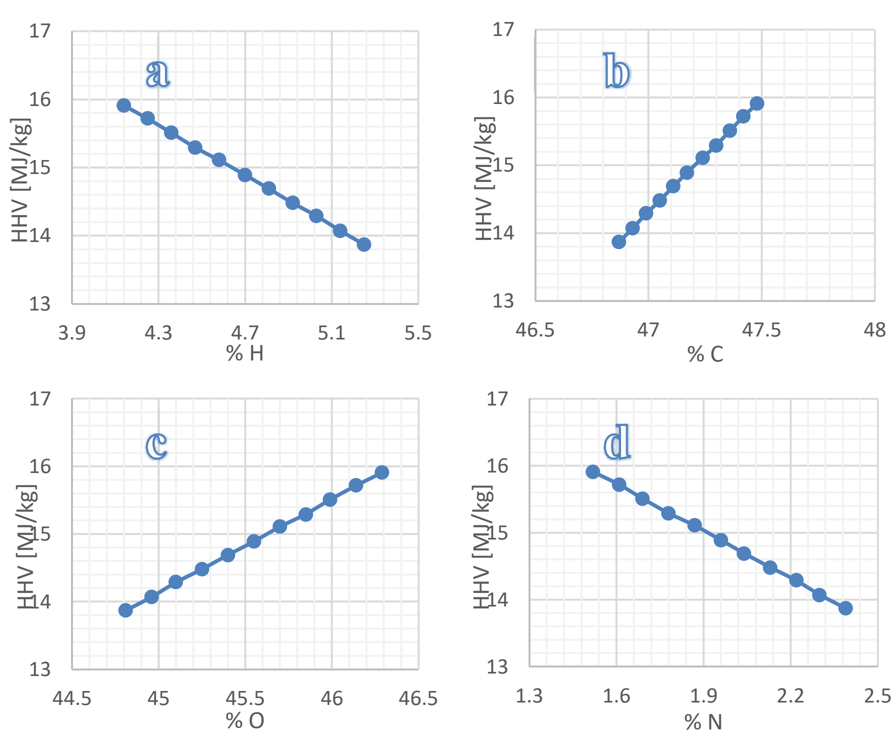

Figure 5. Relationships between the gross calorific values and the: (a) hydrogen contents, (b) carbon contents, (c) oxygen contents, and (d) nitrogen contents.

the energy resources to be considered for microgrid electrification, would make the two wastes some economically viable energy resource options for rural electrification in the south-western region of the country where cocoa and kolanut farming is prominently practised.

While the projection on the quantity of electrical energy accruable from the two agro-residues, as estimated in this study, mainly serves as pointers to electricity potentials of the biomass, actual experimentation of electricity generation from the materials may be required to substantiate the claim. Further study may prototype power generation from the wastes for necessary trial testing.

Declarations

Author contribution statement

Titus O. Ajewole: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Francis B. Elehinafe: Performed the experiments; Wrote the paper.

Oyetunji B. Okedere: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Tobiloba E. Somefun: Analyzed and interpreted the data.

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Data availability statement

No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

[1] W. Arowolo, P. Blechinger, C. Cader, Y. Perez, Seeking workable solutions to the electrification challenge in Nigeria: minigrid, reverse auctions and institutional adaptation, Energy Strategy Rev 23 (2019) 114–141.

[2] World Bank, Access to Electricity (% Population) – Nigeria. Sustainable Energy for All (SE4ALL), 2019. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=NG&most_recent_year_desc=false. (Accessed 29 June 2021).

[3] T.O. Ajewole, O.D. Momoh, O.D. Ayedun, M.O. Omoigui, Optimal component configuration and capacity sizing of a mini integrated power system, Environ. Qual. Manag. 28 (2019) 57–62.

[4] T.O. Ajewole, O.E. Olabode, K.O. Alawode, M.O. Lawal, Small-scale electricity generation through thermal harvesting in rooftop photovoltaic picogrid using passively cooled heat conversion devices, Environ. Qual. Manag. 29 (2020) 95–102.

[5] N. Avila, J.P. Carvallo, B. Shaw, D.M. Kammen, The Energy challenge in Sub-saharan Africa: A Guide for Advocates and Policy Makers: Part 1: Generating Energy for Sustainable and Equitable Development, Oxfam Research Backgrounder series, 2017. https://www.oxfamamerica.org/static/media/files/ox fam-RAEL-energySSA-pt1.pdf. (Accessed 29 June 2021).

[6] T.O. Ajewole, M.O. Lawal, M.O. Omoigui, Development of a lab-demo facility for wind energy conversion systems, Int. J. Ener. Conv. 4 (2016) 1–6.

[7] T.O. Ajewole, K.O. Alawode, M.O. Omoigui, W.A. Oyekanmi, Design validation of a laboratory-scale wind turbine emulator, Cog. Eng. 4 (2017) 1, 1.

[8] T.O. Ajewole, W.A. Oyekanmi, A.A. Babalola, M.O. Omoigui, RTDS modeling of a hybrid-source autonomous electric microgrid, Int. J. Emerg. Elec. Power Syst. 18 (2017) 1–11.

[9] B.G. Taphee, Y.H. Musa, I.P. Vonsanka, Economic efficiency of cocoa production in gashaka local government area in Taraba state of Nigeria, Mediterr. J. Soc. Sci. 6 (2015) 1–7.

[10] I. Ndagi, F.D. Babalola, I.U. Mokwunye, C.F. Anagbogu, I.A. Aderolu, O. Ugioro, E.U. Asogwa, M. Idrisu, F.C. Mokwunye, Potentials and challenges of kolanut production in Niger State, Nigeria, Int. Scholarly Resea. Notices. (2012) 492394.

[11] O. Taiwo, T. Shitu, J. Lawal, A. Yahaya, T. Okeowo, Analysis of factors affecting the marketing of kola nut in Ogun Sate, Nigeria, Asian J. Agric. Ext., Econs & Soc. 19 (2017) 1–6.

[12] M. Sosan, J. Oyekunle, Organochlorine pesticide residue levels and potential human health risks in kolanuts from selected markets in Osun State, Southwestern Nigeria, Asian J. Chem. Sci. 2 (2017) 1–11.

[13] Food and Agricultural Organization of the United Nations, FAOSTAT, 2019. http://www.fao.org/faostat/en/#data/QC. (Accessed 29 June 2021).

[14] M.A. Nasution, T. Herawan, M. Rivani, Analysis of palm biomass as electricity from palm oil mills in North Sumateria, Ener. Proce 47 (2014) 166–172.

[15] C.M. Sastre, E. Maletta, Y. González-Arechavala, P. Ciria, A.M. Santos, A. DelVal, P. Pérez, J. Carrasco, Centralized electricity production from winter cereals biomass grown under Central-Northern Spain conditions: global warming and energy yield assessments, Appl. Energy 114 (2014) 737–748.

[16] J. Chaula, M. Said, G. John, S. Manyele, C. Mhilu, Modelling the suitability of pine sawdust for energy production via biomass steam explosion, Smart Grid Renew. Energy 5 (2014) 1–7.

[17] D. Champier, J.P. Bedecarrats, M. Rivaletto, F. Strub, Thermo-electric power generation from biomass cooking stove, Energy 35 (2010) 935–942.

[18] S.M. O'Shaughnessy, M.J. Deasy, C.E. Kinsella, J.V. Doyle, A.J. Robinson, Small scale electricity generation from a portable biomass cooking stove: prototype design and preliminary results, Appl. Energy 102 (2013) 374–385.

[19] S.M. O'Shaughnessy, M.J. Deasy, J.V. Doyle, A.J. Robinson, Field trial testing of an electricity-producing portable biomass cooking stove in rural Malawi, Ener. Sust. Dev. 20 (2014) 1–10.

[20] J.A. Ruiz, M.C. Juarez, M.P. Morales, P. Munoz, M.A. Mendivil, Biomass gasification for electricity generation: review of current technology barriers, Renew. Sustain. Energy Rev. 18 (2013) 174–183.

[21] T.P. Keane, C.N. Brodsky, D.G. Nocera, Oxidative degradation of multi-carbon substrates by an oxide cobalt phosphate catalyst, Organometallics 38 (2019) 1200–1203.

[22] D. Zinla, P. Gbaha, P.M.E. Koffi, B.K. Koua, Characterization of rice, coffee and cocoa crops residues as fuel for thermal power plant in Côte d'Ivoire, Fuel 283 (2021) 119250.

[23] M. Syamsiro, H. Saptoadi, B.H. Tambunan, N.A. Pambudi, A preliminary study on the use of cocoa pod husks as a renewable source of energy in Indonesia, Ener. Sust. Dev. 16 (2012) 74–77.

[24] T. Raj, M. Kapoor, R. Gaur, J. Christopher, B. Lamba, D.K. Tuli, R. Kumar, Physical and chemical characterization of various Indian agriculture residues for biofuels production, Energy Fuels 29 (2015) 3111–3118.

[25] M. Billen, Proximate and ultimate analysis before and after physical & chemical demineralization. World Multidisciplinary Earth Sciences Symposium, IOP Conf. Ser. Earth Environ. Sci. 362 (2019), 012092.

[26] G. Cavalaglio, F. Cotana, A. Nicolini, V. Coccia, A. Petrozzi, A. Formica, A. Bertini, Characterization of various biomass feedstock suitable for small-scale energy plants as preliminary activity of biocheaper project, Sustain. Times 12 (2020) 6678.

[27] J. Cai, Y. He, X. Yu, S.W. Banks, Y. Yang, X. Zhang, Y. Yu, R. Liu, A.V. Bridgwater, Review of physicochemical properties and analytical characterization of lignocellulosic biomass, Renew. Sustain. Energy Rev. 76 (2017) 309–322.

[28] A.P. Singh Chouhan, A. Sarma, Critical analysis of process parameters for bio-oil production via pyrolysis of biomass: a review, Recent Pat. Eng. 7 (2013) 98–114.

[29] Y. Shao, J. Wang, F. Preto, J. Zhu, C. Xu, Ash deposition in biomass combustion or co-firing for power/heat generation, Energy 5 (2012) 5171–5189.

[30] H. Cheng, Y. Hu, Municipal solid waste (MSW) as a renewable source of energy: current and future practices in China, Bioresour. Technol. 101 (2010) 3816–3824.

[31] M.L. De Souza-Santos, K. Ceribeli, Technical evaluation of a power generation process in consuming municipal solid waste, Fuel 108 (2013) 578–585.

[32] B. Miller, D. Tillman, Combustion Engineering Issues for Solid Fuel Systems, first ed., Academic Press, Burlington, 2008.

[33] F.B. Elehinafe, O.B. Okedere, B.S. Fakinle, J.A. Sonibare, Assessment of sawdust of different wood species in Southwestern Nigeria as source of energy, Energy Sources, Part A Recovery, Util. Environ. Eff. 39 (2017) 1901–1905.

[34] F.B. Elehinafe, O.B. Okedere, O.A. Odunlami, T.E. Oladimeji, A.O. Mamudu, J.A. Sonibare, Comparative study of non-metallic contents of sawdust of different wood species and coal species in Nigeria, Pet. & Coal 61 (2019) 1183–1189.

[35] M. Lajili, L. Limousy, M. Jeguirim, Physicochemical properties and thermal degradation characteristics of agro-pellets from olive mill by-products/sawdust blends, Fuel Process. Technol. 126 (2014) 215–221.

[36] T.O. Ajewole, O.K. Alawode, L.K. Abidoye, O.B. Oluwasanmi, Determination of the thermo-electric potentials of some local sawdust as energy feedstock for electric power generation, UNIOSUN J. Sci. 2 (2017) 105–112.

[37] A.E. Ray, C. Li, V.S. Thompson, D.L. Daubaras, N.J. Nagle, D.S. Hartley, Biomass blending and densification: impacts on feedstock supply and biochemical conversion performance, in: S.T. Jaya (Ed.), Biomass Volume Estimation and Valorization for Energy, IntechOpen, 2017.

[38] T. Zeng, A. Pollex, N. Weller, V. Lenz, M. Nelles, Blended biomass pellets as fuel for small scale combustion appliances: effect of blending on slag formation in the bottom ash and pre-evaluation options, Fuel 212 (2018) 108–116.
[39] C.W. Edmunds, E.A.R. Molina, N. André, C. Hamilton, S. Park, O. Fasina, S.S.S. Adhikari-Kelley, J.S. Tumuluru, T.G. Rials, N. Labbé, Blended feedstocks for thermochemical conversion: biomass characterization and bio-oil production from switch grass-pine residues blends, Front. Ener. Resea. (2018) 79.
[40] S. Acar, A. Ayanoglu, Determination of higher heating values (HHVs) of biomass fuels, Ener. Educ. Sci. & Techn. Part A: Ener. Sci. & Resour. 28 (2012) 749–758.
[41] D.R. Nhuchhen, P. Abdul-Salam, Estimation of higher heating value of biomass from proximate analysis: a new approach, Fuel 99 (2012) 55–63.
[42] T. Walser, T. Limbach, R. Brogioli, E. Erismann, L. Flamigni, B. Hattendorf, M. Juchli, F. Krumeich, C. Ludwig, K. Prikopsky, Persistence of engineered nanoparticles in a municipal solid-waste incineration plant, Nat. Nanotechnol. 7 (2012) 520–524.
[43] O.M. Aderoju, A.B. Oke, G.I. Agbaje, A.G. Dias, Plastic waste for electrical power generation: a case study in Nigeria, Revista de Gestão Ambiental e Sustentabilidade 8 (2019) 538–553.
[44] D.Y. Tsunatu, T.S. Tickson, K.D. San, J.M. Namo, Municipal solid waste as alternative source of energy generation: a case study of Jalingo metropolis, Taraba State, Nigeria, Int. J. Eng. Technol. 5 (2015) 185–193.
[45] L. Zhijia, L. Xing'e, F. Benhua, J. Zehui, C. Zhiyong, Y. Yan, The properties of pellets from mixing bamboo and rice straw, Renew. Energy 55 (2013) 1–5.
[46] L.S. Nikolaisen, P.D. Jensen, Biomass feedstocks: categorization and preparation for combustion and gasification, in: Rosendahl (Ed.), Biomass Combustion Science, Technology and Engineering, Woodhead Publishing, 2013, pp. 36–57.
[47] A. Adamovics, R. Platace, I. Gulbe, S. Ivanovs, The content of carbon and hydrogen in grass biomass and its influence on heating value, in: Proceedings of the 17th International Scientific Conference on Engineering for Rural Development, Jelgava, 2018, pp. 1277–1281.
[48] P. Basu, Biomass Gasification and Pyrolysis Practical Design and Theory, Elsevier, Oxford, 2010.
[49] M. Mann, P. Spath, A life cycle assessment of biomass co-firing in a coal-fired power plant, J. Clean Prod. Proce. 3 (2001) 81–91.
[50] A. Biwas, Thermochemical Behaviour of Pre-treated Biomass. Licentiate Thesis in Energy and Furnace Technology, KTH, Stockholm, 2012.
[51] E. Keybondorian, H. Zanbouri, A. Bemani, T. Hamule, Estimation of the higher heating value of biomass using proximate analysis, Energy Sour. Part A Recovery, Util. Environ. Eff. 39 (2017) 2025–2030.
[52] X. Qian, S. Lee, A. Soto, G. Chen, Regression model to predict the higher heating value of poultry waste from proximate analysis, Resour. 7 (2018) 1–14.
[53] R.G. Santos, J.M. Bordado, Design of simplified models for the estimation of higher heating value of refuse derived fuels, Fuel 212 (2018) 431–436.
[54] O. Alvesa, M. Gonçalvesa, P. Britob, E. Monteirob, Modelling higher heating value of different separated fractions from municipal and construction and demolition wastes, in: Proceedings of the 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. Portugal, 2018, pp. 2–11.