Agronomy Research **17**(6), 2180–2186, 2019
https://doi.org/10.15159/AR.19.165

The potential of energy recovery from by–products of small agricultural farms in Nigeria

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Abstract. Agricultural by–products are renewable energy sources from which essential amount of energy can be recovered, which can be used to replace the use of conventional fossil fuel, reduces the potential of greenhouse gas (GHG) emission and at the same time reduces deforestation, especially in rural areas. Energy values of biomass from small Agricultural farms, in particular waste generated from different tropical crops, viz; Maize, Millet, Rice, Sorghum and Groundnut were determined, to ascertain their potentials as alternative fuel sources for rural use. The materials were found to be of importance judging by their combustion potentials in all the forms investigated. The Energy values of the by-products considered ranged between 11.68 MJ kg^{-1} to 17.48 MJ kg^{-1} with Groundnut pods and millet husk having the highest and least respectively. Moisture and ash had effect on the energy values of these biomass. Our results are relevant to the problems posed by the management of farm residues in developing countries.

Key words: by–products, energy, tropical biomass.

INTRODUCTION

Global increase in human population leads to an increase in Agricultural production, which as well results to rise in the production of Agricultural by–products at both farm and industrial levels.

Agricultural waste comprises both natural (organic) and non–natural wastes which can either be solid, liquid and slurries resulting from growing and first processing of Agricultural products. Uncontrolled or improper handling of which may lead to environmental pollution (Zhang et al., 2012). Crop residues include: straw from barley, rice, soy bean and wheat; Stover from maize; bagasse from sugar cane (Bentsen et al., 2014), rice husk, corn cobs, cocoa pods, fruits shell (Titiloye et al., 2013), sorghum and millet husk and groundnut pods.

Potential energy can be derived from Agricultural wastes which are produced through Agricultural practices (Bentsen et al., 2014). The type of waste, its quantity and geographical location, and also the handling practice by local farmers determines the ways through which the energy can be recovered (Jana & De, 2015). Energy values of different Agricultural wastes vary and this informs the methods and techniques adopted in their use (Titiloye et al., 2013). Physico–chemical characteristics of such materials offer means for such assessment (McKendry, 2002b). For example, rice straw is used as cattle fodder and may be burnt or gasified for heating or electricity generation (Jana & De, 2015). Renewable sources of energy offer a means for mitigating and reducing the effects of global warming (McKendry, 2002a).

Maize, rice, millet, Sorghum and groundnut are among the highly produced crops in Nigeria from which different by–products can be obtained which are of importance as biomass feedstock. Relative yield of maize cobs is between 10% and 20% of total crop mass, at 10%–12% moisture levels, normally left on farms after threshing. In rural areas of developing countries, such perceived by–product may be utilized for direct combustion purposes (Martinov et al., 2011).

Maize is the most widely cultivated cereal crop with estimated global annual production of 717 metric tons (Ranum et al., 2014). Maize cobs which comprise 18.7% of the total grain mass (Blandino et al., 2016), are currently being used for heating in some parts of Europe (F. John Hay, 2015) and as animal bedding. Rice with an estimated global annual production of 120 million tons (Abbas & Ansumali, 2010), whose husk is essentially 20% of the crop's volume is seldom considered to be fodder since it is rich in silica and decomposes slowly. Through direct combustion, this by–product may be utilized for heating and power generation (Dunnigan et al., 2018). Millet is a subsistence crop mostly cultivated for local consumption, with an estimated global production of 28 tons year^{-1} (FAO and ICRISAT, 1996). Millet husks left on the farm after harvest often become hosts for crop disease pathogens and it may be helpful to modify them for combustion (Abba et al., 2017). Groundnut (*Arachis hypogaea* L.) is one of the most important cash crops of West Africa and a source of edible vegetable oil, adaptable also for biofuel purposes (Baributsa et al., 2017). Its global annual production was estimated as 34 million metric tons. Nautiyal (2002) and the pods are 20%–30% by weight of the seed crop, often discarded or burnt after threshing, constituting serious pollution problem (Deeba et al., 2017). With nearly 57 million tons of annual production, sorghum is a rich source of easily sourced, inexpensive and readily available biomass feedstock (Monteiro et al., 2012; Wizi et al., 2018).

Over 2.5 billion people depends on traditional use of biomass as their primary fuel for cooking in developing countries (Toklu, 2017), transformation of which will be more efficient and bio friendly. Biomass with low moisture content are more appropriate for thermal conversion technology, whereas those with high moisture content are recommended for fermentation and anaerobic digestion (Garivait et al., 2006).

The by-products are often discarded or burn in the farm thereby polluting the environment and contributing to global warming, knowing the energy value of which will help in determining appropriate way of management for value addition.

MATERIALS AND METHODS

Materials

Tropical agricultural by–products which were dried husks of rice, millet and sorghum, pods of groundnut and cobs of maize at moisture content of less than 10%, in dry basis obtained from different parts of Bauchi state, Nigeria were used. A representative sample of each was collected and transported to Czech Republic for the study. Three replications of each test were carried out and the mean values were reported. The energy potential of which were determined under two different states; as received and dry basis.

Methods

The moisture content of the raw by–products were determined according to EN ISO 18134–3:2015, using Memmert UF30 laboratory oven at 105ºC, which were calculated using equation (1) (Havrland et al., 2013; Pňakovič & Dzurenda, 2015).

$$w = \left(\frac{m_0 - m_1}{m_0}\right) \cdot 100 \quad (1)$$

where w – moisture content; m_0 – mass of the samples before drying and m_1 – mass of the samples after drying.

Samples were milled to 1mm screen fraction, using Retsch SM100 Milling Machine. An automated oven, LECO TGA701 was used in determining moisture and ash contents of the biomass, in accordance with the EN ISO 18122:2015 standard (Ivanova et al., 2018). Higher Heating Value of the biomass were measured according to ISO 1928: 2009 standard, using LECO AC 600 Calorimeter. Lower Heating Value of dry basis of the biomass samples were calculated using Eq. (2) (Pňakovič & Dzurenda, 2015).

$$LHV = \left(HHV - 212w_{Hd} - 0.8 \cdot (w_{Od} + w_{Hd})\right) \cdot (1 - 0.01M_t) - 24.43M_T \quad (2)$$

where LHV – lower heating value (MJ kg^{-1}); HHV – higher heating value (MJ kg^{-1}); w_{Od} – oxygen content in dry state (%wt.); w_{Hd} – hydrogen content in dry state (%wt.); M_T – target moisture (0% for dry state).

Ultimate analysis of the biomass were then carried out to determine C, H, O, N and S content (McKendry, 2002a; Ivanova et al., 2018) using Leco CHN628/628 S.

RESULTS AND DISCUSSION

Proximate and ultimate compositions of as received and dry samples of different biomass materials studied are presented in Tables 1 and 2 along with their associated measures of uncertainty at confidence levels of 95%.

The moisture level of the by–products sampled was approximately 7% in dry basis. For the samples analyzed in as received basis, Groundnut pods and Rice husk had the highest and lowest heating values (Table 1). Ash content in rice husks and millet husk was 22% and 30% respectively, which are higher than the levels observed in other samples whose ash contents were below 10% (Table 1). Higher ash content can be attributed to contamination with sand or dust particles during threshing and sample collection (Titiloye et al., 2013; Pňakovič & Dzurenda, 2015).

Carbon content was higher in the samples with low ash content. Energy values were also higher in materials with low ash content and high carbon content (Table 1). Energy values of the by–products considered ranged between 11.68–17.48 MJ kg^{-1}. Groundnut pods had significantly higher energy values, compared to other materials (Table 1).

With the elimination of moisture from product samples, Carbon contents improved significantly, though, no significant change in ash contents was observed for all of the biomass tested (Table 2). Lower moisture content of the biomass favor better thermal conversion (Demirbas, 2007; Titiloye et al., 2013; Palackaa et al., 2017).

Table 1. Proximate and ultimate composition of the analysed biomass together with their respective uncertainties

Sample	w %wt.	A %wt.	C %wt.	H incl. water %wt.	H in combustable %wt.	N %wt.	S %wt.	O %wt.	HHV MJ kg^{-1}	LHV MJ kg^{-1}
Rice	6.63 ± 0.11	22.02 ± 0.15	35.96 ± 0.38	5.37 ± 0.06	4.61 ± 0.06	0.86 ± 0.03	< 0.05	29.91 ± 0.42	14.48 ± 0.04	13.32 ± 0.05
Sorghum	7.26 ± 0.09	8.42 ± 0.69	42.29 ± 0.57	5.78 ± 0.08	4.97 ± 0.08	0.41 ± 0.07	< 0.05	36.65 ± 0.90	15.93 ± 0.28	14.66 ± 0.16
Groundnut	7.92 ± 0.07	3.19 ± 0.25	47.68 ± 0.26	6.14 ± 0.07	5.26 ± 0.07	1.14 ± 0.05	< 0.05	34.83 ± 0.37	18.81 ± 0.07	17.48 ± 0.07
Maize	7.56 ± 0.05	1.66 ± 0.17	45.54 ± 0.26	6.16 ± 0.07	5.32 ± 0.07	0.41 ± 0.05	< 0.05	39.52 ± 0.33	17.59 ± 0.16	16.25 ± 0.16
Millet	5.37 ± 0.24	30.43 ± 2.35	33.34 ± 1.48	4.45 ± 0.21	3.85 ± 0.18	0.85 ± 0.12	< 0.05	26.36 ± 1.94	12.65 ± 0.48	11.68 ± 0.48

w – moisture content; A – ash content; C – carbon content; H – hydrogen content; N – nitrogen content; S – sulfur content; O – oxygen content; HHV – higher heating value; LHV – lower heating value.

Table 2. Composition of dry biomass

Sample	A^d %wt.	C^d %wt.	H^d %wt.	N^d %wt.	S^d %wt.	O^d %wt.	HHV MJ kg^{-1}	LHV MJ kg^{-1}
Rice	23.58 ± 0.16	38.52 ± 0.41	4.94 ± 0.07	0.92 ± 0.03	< 0.05	32.04 ± 0.45	15.52 ± 0.05	14.44 ± 0.05
Sorghum	9.08 ± 0.74	45.60 ± 0.62	5.36 ± 0.08	0.44 ± 0.08	< 0.05	39.52 ± 0.97	17.17 ± 0.17	16.00 ± 0.17
Groundnut	3.46 ± 0.27	51.78 ± 0.28	5.71 ± 0.07	1.24 ± 0.05	< 0.05	37.82 ± 0.40	20.44 ± 0.08	19.19 ± 0.08
Maize	1.79 ± 0.19	49.26 ± 0.29	5.75 ± 0.07	0.44 ± 0.05	< 0.05	42.75 ± 0.35	19.03 ± 0.17	17.78 ± 0.17
Millet	32.16 ± 2.48	35.23 ± 1.56	4.07 ± 0.20	0.89 ± 0.13	< 0.05	27.85 ± 2.04	13.37 ± 0.50	12.48 ± 0.51

A^d – ash content in dry state; C^d – carbon content in dry state; H^d – hydrogen content in dry state; N^d – nitrogen content in dry state; S^d – sulfur content in dry state; O^d – oxygen content in dry state; HHV – higher heating value; LHV – lower heating value.

Inorganic residue ash of the dry biomass with their respective heating values and ultimate composition are presented in Table 2. Ash content of maize cobs was the least (1.79%wt). Ash content of rice husks was 23.58%; this is less than the value reported by (Titiloye et al., 2013) but comparable to that of commercial coal which falls within the range of 5%–20%wt (Palackaa et al., 2017). In this state, energy values of the pods of groundnut were the highest, being 19.19 MJ kg^{-1} while those of dried millet husks stood at 12.48 MJ kg^{-1}, comparable to values reported in similar works (Titiloye et al., 2013). These values represent significant proportions and potentials for thermal conversion.

Nitrogen levels in the feedstock were low, which indicates a favorable risk of associated oxide emission during combustion (Pňakovič & Dzurenda, 2015). Sulfur contents were also negligible.

The energy value of all the by–products tested increases with decreasing moisture content (Demirbas, 2007; Titiloye et al., 2013; Palackaa et al., 2017; Paudel et al., 2017), which can be attributed to low carbon and oxygen content of the undried samples.

The energy value of Groundnut shell and Rice husk are higher than what was reported in similar researches as presented in Table 3. Similar values were discovered by Demirbas (2007) for heating value of Maize cobs, with other reported values less than what was obtained in this research (Table 3).

Table 3. Heating value of Agricultural by-products compared with previous researches

Sample	w %wt.	A %wt.	HHV MJ kg^{-1}	LHV MJ kg^{-1}	Source
Rice husk	**6.63**	**22.02**	**14.48**	**13.32**	
	8.59	24.71	14.08	-	(Titiloye et al., 2013)
Sorghum husk	**7.26**	**8.42**	**15.93**	**14.66**	
Groundnut pods	**7.92**	**3.19**	**18.81**	**17.48**	
	12	3.47	17.12	-	(Oyelaran, 2014)
	10.3	6.0	16.4	-	(Onuegbu et al., 2012)
Maize cobs	**7.56**	**1.66**	**17.59**	**16.25**	
	8.72	2.96	16.24	-	(Titiloye et al., 2013)
	5.7	1.3	17.7	16.2	(Demirbas, 2007)
	12.2	3.3	16.4	-	(Onuegbu et al., 2012)
Millet husk	**5.37**	**30.43**	**13.37**	**12.48**	

w – moisture content; A – ash content; HHV – higher heating value; LHV – lower heating value.

The by-products can either be combusted directly or transformed into different forms of biofuel (solid liquid or gas) using different conversion technologies (Toklu, 2017). Improvement through pelletization can reduce moisture content, increase bulk density and as well increases the heating value (Rosillo-Calle et al., 2007; Jagustyn et al., 2011), which will ensure efficient utilization in rural areas.

CONCLUSIONS

The energy value of some tropical Agricultural by–products were investigated under two different states. Heating values increases with decreasing moisture content and decreases with increasing ash content. Carbon and oxygen also increases with decreasing moisture content. Dry basis of all the samples tested has the highest heating value, while as received basis has the least. The biomass have favorable heating values under all the two states, they can therefore be efficiently used for combustion through pelletization.

ACKNOWLEDGEMENTS. This study was supported by the Internal Grant Agency of the Faculty of Engineering, Czech University of Life Science Prague, grant number: 2018:31170/1312/3123.

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