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Use of Banana Culture Waste to Produce Briquettes

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The banana culture wastes, leaf and pseudostem, can be used to produce briquettes as fuel for energy generation. The northern region of the Santa Catarina State in Brazil, more precisely in the Joinville city, presents a significant production of bananas, with a harvest of 24,300 t (2010/2011), with 900 hectares of planted area. From the total of harvested bananas 1.5 t of leaves and 2.5 t of pseudostem are generated per ton of produced banana. In this context, this article presents the preparation steps and characterization of banana wastes (leaves and pseudostem) for the production of briquettes. The wastes and briquettes were evaluated by chemical analysis, high heating value (HHV) as well as by thermogravimetric analysis (TGA) and differential thermal analysis (DTA). It was also evaluated the mechanical compressive strength of the briquettes. The moisture content in the wastes for briquetting must be between 8 and 15 %. The banana leaves and pseudostem showed carbon contents of 43.28 % and 38.92 %. The HHV of the leaves was approximately 17.10 MJ/kg and of the pseudostem it was about 13.70 MJ/kg. Under combustion, the wastes showed maximum release of energy at approximately 580 °C and briquettes at 300 °C. The briquettes of pseudostem and leaves presented compressive strength of 15 MPa and 5.3 Mpa, respectively. The thermal properties and physicochemical characteristics of these wastes demonstrate that they are potential candidates to produce briquettes as fuel in several applications.

1. Introduction

Biomass is one of the sources for energy production with the greatest growth potential in the coming years and can be easily obtained from agricultural production, which generates large amounts of waste. The use of agricultural and agro-industrial wastes as biomass fuel for power generation is being increasingly studied and could be an alternative solution to the problems related to them. These wastes can be availed as briquettes and pellets for use in combustion and gasification processes in power generation. Suzdalenko et al. (2011) evaluated the effect of co-gasification of the biomass pellets (wood and straw) with gas on the thermal degradation of biomass. The fuel gas generated (mixture of CO, H_2 e CH_4) can be used in internal combustion engine for power production.

In the briquetting process, particles of solid materials are pressed to form blocks with defined shape and dimensions. Briquettes produced from this waste at low cost are an excellent source to produce cheap energy following an environmentally correct way and they are, in many cases, ideal for replacing fossil fuels in use today, with significant economic and environmental advantages (Yamaji et al., 2010).

Several biomasses are being studied for the production of briquettes. Kaliyan and Morey (2010) studied the densification characteristics of corn cobs. Oladeji (2010) evaluated the fuel characterization of briquettes produced from corncob and rice husk resides. The preparation and characterization of solid biomass fuel made from rice straw and rice bran were studied by Chou et al. (2009). Yumak et al. (2010) produced briquettes from soda weed (*Salsola tragus*) to be used as a rural fuel source. The production of biobriquettes from carbonized brown seaweed was evaluated by Acma et al. (2013) and the effects of briquetting pressure on banana-peel briquettes and on banana waste in northern Thailand by Wilaipon (2009). Among the advantages of using briquettes, it can be mentioned: reduction of the deforestation, due to the substitution of

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the wood generally used; production of cheaper energy; reduction of the environmental impact caused by the large amount of wastes and its destination; and reuse of leftover materials.

The north coast of Santa Catarina State in Brazil, more precisely in the region of Joinville city, has great agricultural potential, especially in the case of banana production, whose crop year 2010/2011, produced 24,300 t of bananas representing 900 hectares of planted area, with an average yield of 27,000 kg/ha (IBGE, 2011). According to Soffner (2001), the banana generates a significant amount of wastes, approximately 200 t/ha/year, since each plant produces one to five bunches of bananas. The most significant waste and more bulky are leaves, pseudostem and stalk. After the harvest, from the waste produced in the greatest quantity, the pseudostem of the banana palm is usually left in the soil to be used as fertilizer or mixed with the rejected fruit for the production of animal feed (Tock et al., 2010) and the leaves are used for packaging foods or for cooking. Aiming the reuse of wastes, in this work, banana leaves and pseudostem were used and characterized to produce briquettes as fuel in several applications.

2. Experimental

2.1 Sample Preparation

Samples of dried banana leaves were obtained directly from banana trees and only the leaves that were already dried were collected. The pseudostem was obtained only from plants that had been cut for obtaining fruit and were decomposing in the soil. By having high humidity, pseudostem was pressed in a hydraulic press to remove the largest liquid fraction, and after this process, it was dried in a forced ventilation muffle at 60 ºC for 24 h. Both samples were milled so that a powder with an average particle size of 2.5 mm was obtained.

2.2 Briquetting of wastes

The briquettes were produced in a briquetting hydraulic press – BHP, using compaction pressure of 18 MPa and compression times of 0.6 and 1 s. The dimensions of the briquettes produced were 50 mm diameter and 50 mm length.

2.3 Waste and briquettes characterization

Samples of waste and briquettes were characterized by proximate chemical analysis, following procedures of ASTM E1871-82 (2006) for moisture, ASTM E872-82 (2006) for volatile materials, ASTM E1755-01 (2007) for ash and ASTM E1756-08 (2008) for total solids and fixed carbon; elemental chemical analysis (carbon, nitrogen and hydrogen) by elemental analyzer and sulfur by atomic emission spectrometer with inductively coupled plasma (ICP-AES); Thermogravimetric Analysis, TGA and Differential Thermal Analysis, DTA (Netzsch STA 449F3) under oxidizing atmosphere (synthetic air), temperature range of 22 up to 900 ºC and heating rate of 10 °C/min.; and high heating value by bomb calorimeter, Parr model 1241, following the ABNT MB-2850 and ABNT NBR 8628. The approximate analysis was performed in triplicate and elemental analysis and heating value in duplicate.

The briquettes were subjected to mechanical tests by using an Emic Universal test machine, with a load speed of 1 mm/min. For mechanical tests six briquettes were used for each waste. The same briquette samples were also used, previously, to determine the bulk density (relation between mass and volume of the briquettes).

3. Results

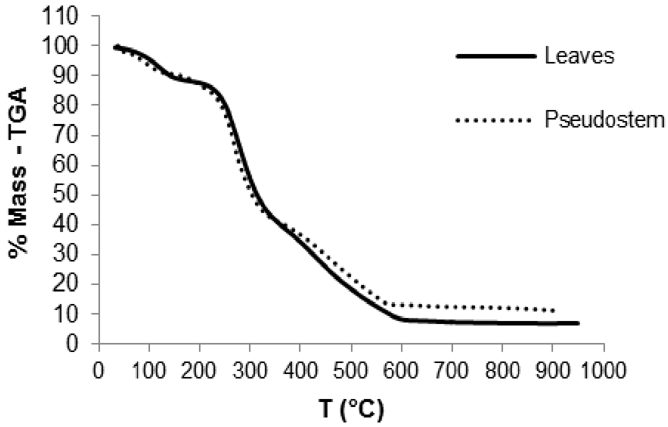
Table 1 presents the results of the high heating value (HHV) and the chemical analysis, listing the average moisture (M), volatile matter (VM), fixed carbon (FC), ash and contents, and CNHS elemental composition of the samples.

Both leaves wastes and the produced briquettes had the highest values of HHV, i.e., 17.10 MJ/kg and 17.7 MJ/kg, respectively. The pseudostem showed slightly lower heating value, i.e., 13.70 MJ/kg for the residue and 14.9 MJ/kg for the briquette. These results can be explained by the higher moisture content present in pseudostem and leaves, which have higher levels of carbon and hydrogen. The values of HHV are similar to those of other lignocellulosic biomass studied (Wilaipon, 2009; Morais et al., 2006; Felfli et al., 2011). Briquettes of the cupuaçu peel (Brazilian fruit) also showed satisfactory results for power generation, with heating value of 26.7 MJ/kg (Santos et al., 2004).

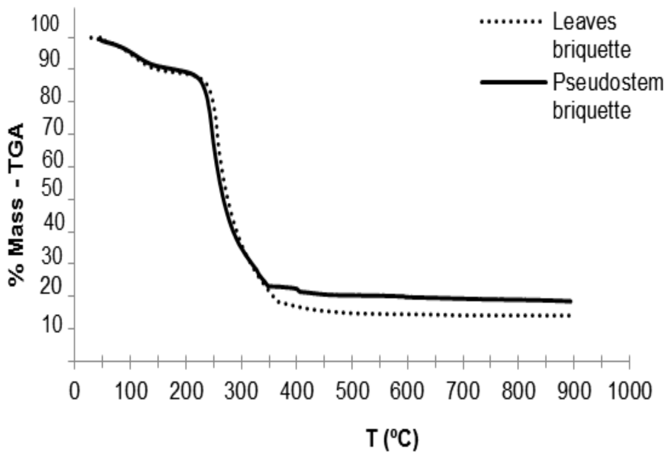
Table 1: High heating values and chemical compositions of wastes and briquettes.

Measurements	Leaves	Pseudostem	Leaves Briquette	Pseudostem briquette
HHV (MJ/kg)	17.10 ± 0.30	13.70 ± 0.10	17.70 ± 0.20	14.90 ± 0.10
M (%)	7.91 ± 0.30	10.89 ± 0.2	7.17 ± 0.31	9.74 ± 0.37
VM (%)	78.16 ± 0.80	89.10 ± 0.2	75.30 ± 0.85	71.70 ± 1.13
FC (%)	15.60 ± 0.40	18.0 ± 3.8	18.25 ± 0.43	18.74 ± 0.66
Ash (%)	6.23 ± 0.40	8.04 ± 0.17	10.63 ± 1.09	9.85 ± 0.25
C (%)	43.28 ± 0.14	38.92 ± 0.4	44.28 ± 0.18	37.69 ± 1.80
H (%)	6.23 ± 0.02	5.92 ± 0.12	6.23 ± 0.03	5.58 ± 0.43
N (%)	0.98 ± 0.08	0.38 ± 0.77	0.80 ± 0.01	0.19 ± 0.09
S (%)	0.49	0.49	< 0.3	< 0.3

Agro-industrial wastes (fruit) were used for the production of briquettes by Sant'Anna et al. (2012). The briquettes produced had heating value of 15.7 MJ/kg. High values of HHV indicate that biomass is recommended for direct use as fuel in combustion processes (Fernandes, 2012).
Figure 1 shows TGA curves for waste (a) and briquettes (b) samples. Table 2 shows the stages of thermal degradation and mass losses for the studied wastes and briquettes samples.



(a)



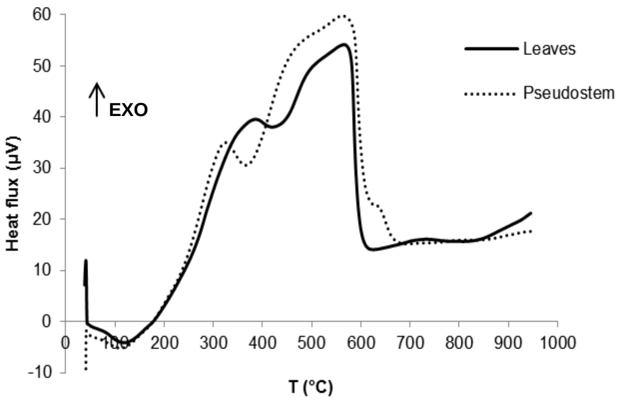
(b)

Figure 1: TGA of leaves and pseudostem wastes (a) and briquettes (b).

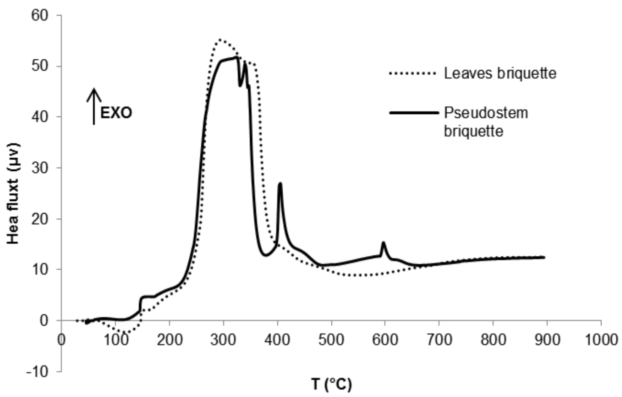
Table 2: Stages of thermal degradation of the samples according to TGA.

	Leaves		Pseudostem		Leaves briquette		Pseudostem briquette	
Stage	T (ºC)	Mass Loss (%)	T (ºC)	Mass Loss (%)	T (ºC)	Mass Loss (%)	T (ºC)	Mass Loss (%)
I	22 – 150	11.79	22 - 150	8.16	22 - 180	7.8	22 - 200	10
II	150 - 600	80.33	150 - 580	76.87	180 - 440	77.2	200 - 420	68.5
III	> 600	7.88	> 580	13.14	> 440	15	> 420	20.4

Thermal degradation for both samples of waste and for the leaves and pseudostem briquettes was very similar, showing three different stages of mass loss. The first stage is related to water loss of samples and the second stage is the degradation of hemicellulose, cellulose and lignin part of the constituents of waste and briquettes. At this stage, also occurs higher mass loss. In the third stage to a temperature of approximately 1,000 °C occurs the degradation of cellulose and lignin remaining.
Figure 2 shows DTA curves of wastes (a) and briquettes (b) samples. Table 3 shows the related thermal events observed for the studied wastes and briquette samples.



(a)



(b)

Figure 2: DTA of leaves and pseudostem wastes (a) and briquettes (b).

Table 3: Thermal events for wastes and briquettes according to DTA.

	Leaves		Pseudostem		Leaves briquette		Pseudostem briquette	
Event	T (ºC)	Reaction	T (ºC)	Reaction	T (ºC)	Reaction	T (ºC)	Reaction
I	50-190	Endothermic	50-190	Endothermic	80-140	Endothermic	90-120	Endothermic
II	190-450	Exothermic	190-380	Exothermic	140-400	Exothermic	120-380	Exothermic
III	450-600	Exothermic	380-700	Exothermic	>400	Stable	380-610	Exothermic
IV	>600	Stable	> 700	Stable	-	-	> 610	Stable

The same way as seen in the TGA curves, the two samples showed similar behavior in both DTA for the waste and for the briquettes. The endothermic event occurred for the samples in the temperature range between approximately 50 and 190 °C corresponds to their moisture loss. The exothermic peaks correspond to the stages of thermal degradation of fractions of hemicellulose, cellulose and lignin gradually. After 600 ºC, the process became stable for the two samples.
The higher energy release was observed for both samples in the second event with peak maximum at approximately 580 °C. The briquettes showed an inferior endothermic event when compared with the wastes because they have lower amounts of moisture. The maximum energy release occurred during the second event for the two samples, with a peak at approximately 300 °C for leaves briquettes and at 320 °C for pseudostem briquettes. The thermal behavior displayed for the two samples indicate potential for the use of biomass waste as fuel in the form of briquettes in the combustion process.
Table 4 shows the results of mechanical compressive strength and density of the banana waste briquettes.

Table 4: Mechanical compressive strength and density of the briquettes.

Measurement	Leaves briquette		Pseudostem briquette	
Compaction time (s)	0.6	1	0.6	1
Compressive strength (MPa)	3.60 ± 2.30	5.30 ± 1.50	9.50 ± 3.60	15.03 ± 3.70
Density (g/cm³)	1.00 ± 0.06	0.99 ± 0.05	1.01 ± 0.08	0.99 ± 0.06

The pseudostem briquettes showed higher compressive strength compared with leaves banana briquettes. This can be explained by the characteristics of biomass. The pseudostem showed a more fibrous structure, and according to Furtado et al. (2010), the higher the proportion of fiber in the entire material, the greater will be its resistance to compression.
Furtado et al. (2010), in studies of forest biomass, obtained briquettes made with compacting pressure of 5 MPa with compressive strength of 16.38 MPa. Oladeji (2010) obtained corncob briquettes with 2.34 MPa compressive strength. The briquettes were produced using a compaction pressure of 10.2 MPa, at hydraulic machine. The values indicate that greater compaction times results in greater strengths. Besides the time, the compaction pressure, the type of biomass and the type of equipment also affect the density and strength of the briquettes. The briquettes obtained can be used as biomass fuel for grills, fireplaces and furnaces.

4. Conclusions

The chemical characterization result of banana leaves and pseudostem samples and briquettes made from these wastes contributed to the understanding of the behavior of these materials for use as biomass fuel. The samples had similar chemical composition between each other and between other lignocellulosic biomass. The TGA and DTA analysis (for the studied waste) in an oxidizing atmosphere show the occurrence of energy absorption due to the moisture still present in the samples at the beginning of the process and high energy delivery, with maximum at approximately 580 °C for wastes and at 300 °C for briquettes. The briquettes had good characteristics and good mechanical strength, especially the pseudostem briquette. However, further studies related to the variables involved in the briquetting process are recommended.

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