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Characterization and feasibility of biomass fuel pellets made of Colombian timber, coconut and oil palm residues regarding European standards

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ABSTRACT

Strong correlation between economic development, energy demand and fossil fuels utilization during last decades has caused some negative impacts worldwide, based on it, the renewable resources for energy production should be employed to mitigate these effects. Nowadays, biomass is one of the most prominent renewable sources, but factors such as low density and high moisture content are some drawbacks. In order to overcome these problems, some companies use different types of biomass to provide solid biofuels with higher energy density, mechanical resistance and standardized dimensions. Wood pellet industry has increased exponentially during last years, faster than timber industries; therefore, new raw materials should be evaluated to guarantee pellets demand in the near future. Some of them are agricultural residues. Colombia is a country with an interesting potential for biomass production because there is a rising generation of agricultural products. This work aims to assess main properties of Colombian timber industry residues, coconut shells and oil palm shells and compare the characteristics of pellets made from these raw materials with European standards. Pellets made from these feedstocks have an average density between 850 and 1025kg·m^{-3}, low ash contents and heating values around 18000kJ·kg^{-1}. Coconut shell pellets have low compression ratios and problems during pretreatment; whereas, sawdust, wood shavings and oil palm shell pellets proved to be an attractive opportunity for pellet industry development in Colombia.

INTRODUCTION

The development of humankind has produced a significant increase of energy consumption. Since the industrial revolution, the demand of electricity and primary energy has augmented, from 71,071PWh in 1973 to 141,304PWh in 2009; likewise, electricity generation boosted up 227%, 6,115PWh in 1973 and 20,055PWh in 2009 (IEA 2011a). Large scale hydropower systems and fossil fuel combustion power systems cover this necessity, causing a lot of environmental, economic, political and social impacts worldwide. Despite of the advantages that these fossil resources have such as high energy density, stability during the combustion process and relative ease for extraction and transportation, there are some serious effects that could not be neglected. Some of them are energy dependency, historical wars, social displacement and maybe the most known one, global warming caused by greenhouse gases.

As a consequence of the unrestricted use of fossil fuels for energy production, CO_2 emissions have gone up (Al-mulali and Binti Che Sab 2012); in 1971 global emissions were about 15,000Mt, whereas in 2009 reached 30,000Mt. In 2009, coal produced 43% of CO_2 emissions while 37% came from oil and 20% from gas (IEA 2011b). An analysis of these emissions by sector shows that the critical issue here is to control emissions produced by electricity and heat sector, its share was 43% of world emissions in 2009 while transport was 23%, industry 20%, residential 6%, and others 10%. Based on these and other problems, some countries have redirected their investments and policies on trying to increase the production of clean energy based on renewable resources.

Between 2004 and 2010 global new investment in renewable energy raised up at high rates, in 2004 it corresponded to 22 Billion USD and seven years later the investment overpassed 210 Billion USD (REN21 2011), this means an increase around 850%. Nevertheless, these investments are not enough to supply the world demand, in terms of electricity renewable resources support 18%, whereas these technologies supply 16% of final energy consumption. More research and development should be done on renewable resources different from big hydropower systems, based on the fact that they cover no more than 3.3% of global electricity production.

Biomass is commonly used for food, feed, fiber, and energy production such as power, heat and liquid biofuels. Among non-hydro renewable resources, biomass is the second most significant source for power production. Wind power existing capacity, at the end of 2010, was 198GW followed by 52GW from biomass. Some of the most attractive characteristics of biomass are: the huge variety of species with adequate characteristics for producing energy (Vassilev et al. 2010), decentralized location of the resources, existing technologies for direct biomass utilization such as biodigestors, gasifiers or stoves (Forero-Núñez et al. 2012a). Moreover, these characteristics generate opportunities for promoting employment creation for technicians and farmers (Di Giacomo and Taglieri 2009).

Colombia has an attractive opportunity to use biomass for energy carrier production based on the facts that several agricultural processes use a significant share of the territory, leading to large quantities of agricultural byproducts, and the necessity of electrical supply at some off-grid areas which could result on more development. Energy potential of coconut shells is $854 TJ \cdot yr^{-1}$ and potential of oil palm solid residues is $6921 TJ \cdot yr^{-1}$ (Forero-Núñez et al. 2012b). This could supply energy demand for 2.1 million people, approximately.

Low density values, non-uniform shapes and sizes, high moisture contents at production place are some of the most serious problems regarding biomass utilization, especially when solid wastes would be employed. Therefore, biomass densification might be applied; this process produces bigger structures from biomass powders; typically, the products are cylindrical solids known as pellets or briquettes with standardized dimensions and high mechanical resistance (Teixeira et al. 2012). Pellet production has some benefits in terms of reduction of storage volume, transportation costs and easy handling and control of feeding systems (Kaliyan and Vance Morey 2009a). Likewise, the lower moisture content and the decreased heterogeneity of the densified biomass also contribute to improve conversion technologies (Erlich et al. 2006).

Wood pellets industry has grown during last years, and different production facilities have been installed worldwide to support demand of Europe, US and Canada. Europe has the largest wood pellet production industry with 670 pellet plants under operation, producing 10 million tonnes in 2009 (REN21 2011). Most of this industry operate with wood residues such as sawdust or wood shavings; although, there are more types of materials that should be explored based on the fact that the timber industry could not increase in the same rate as wood pellet, producing a deficit of raw materials. Some of these alternative materials show fascinating results such as paulownia (Lopez et al. 2012), corn stover, switchgrass (Kaliyan and Vance Morey 2009a) and poplar (Mediavilla et al. 2012). This work aims to analyze proximate and ultimate analysis of Colombian oil palm shells, coconut shells, sawdust, wood shavings, dark coal and the feasibility of pellets produced with these materials in relation to European standards.

MATERIAL AND METHODS

In this study, two kinds of residues of the timber industry were used; the sawdust and wood shavings produced during wood cutting were gathered from carpentry of Universidad Nacional de Colombia. Coconut shells are the external part of the coconut; they were supplied by Amerteck Ltda, Colombia. During palm oil extraction, different solid residues are produced; the most notable are oil palm empty fruit bunches (EFB), fibers and shells. We used oil palm shells provided by the Colombian company “El Palmar del llano”, an oil palm extraction plant (Figure 1).

The feedstock used needs to have small particle sizes and low water content to ensure that produced pellets have better physical characteristics such as strength, durability and final density. The pretreatment of these resources includes some stages; biomass was disposed for natural drying, afterwards they were crushed and ground. Palm oil shells require less energy during grinding because they are more fragile than coconut shells. Sawdust and wood shavings do not require cutting, just drying was done (Figure 2).

During physical characterization, different properties were measured. Bulk density was determined according to ASTM D5057, where a box with known dimensions is filled with the material; afterwards, the samples are weighed. The relation between samples mass and box volume gives the value of this property (Equation 1). The proximate analysis is performed; moisture content is evaluated by following ASTM E871-82, where samples are weighed before and after drying

Figure 1. A-oil palm and B-coconut shells as received.

Figure 2. Biomass employed for solid biofuel production after pretreatment: A-oil palm shells, B-coconut shells, C-sawdust, D-wood shavings.

in an oven at 105°C; this test was completed when the mass difference did not change more than 0.2%. Volatile matter was determined by ASTM E872, where samples were placed in an oven during seven minutes at 950°C; the volatile matter was calculated as the ratio between weight difference and initial dry sample mass. Ash content was measured following the methodology presented on ASTM E1755-01. Samples used for volatile matter evaluation were employed and burned in an oven at 800°C; the relation of remaining mass against initial weight gives the ash content. Fixed carbon was calculated by mass balance on the samples ASTM 1756-08. Each biomass after natural air drying at environment conditions has water, volatile compounds, ash and carbon; therefore, fixed carbon is defined by the difference of initial material weight with moisture content, ash and volatile matter fraction, all of these parameters might be at wet basis.

$$\rho_{in} = \frac{m_{in}}{V} \qquad (1)$$

where m_{in} (kg) was the sample mass weight, ρ_{in} ($kg \cdot m^{-3}$) was the bulk density, and V (m^3) was the sample volume.

Ultimate analysis was performed by the staff of Ingeominas Coal laboratory Colombia; carbon, hydrogen, nitrogen contents were determined according to ASTM D5373-08, where a LECO Truspec CHN analyzer is used. Sulfur content was measured with a LECO SC-32 and S-144DR analyzer based on ASTM D4239-08. Hence, it was possible to calculate elemental oxygen content.

Two methods were followed to determine heating value; the samples were analyzed in a bomb calorimeter in accordance with ASTM D-5865-04, and two analytical relations based on ultimate analysis were used (Stahl and Henrich 2004). The first one corresponds to Dulong Bertholot equation and the second relates the higher heating value of lignocellulose and the ash content. Lower or net heating value (LHV) was calculated by using the Equation 2 according to Obernberger and Thek 2004).

where HHV ($MJ \cdot kg^{-1}$) was the higher heating value, $\%C$ was the carbon mass content, $\%H_2$ was the hydrogen mass content, $\%O_2$ was the oxygen mass content, $\%S$ was the sulfur mass content, $\%\ ash_{db}$ was the ash mass content on dry basis, LHV ($MJ \cdot kg^{-1}$) was the lower heating value, and $\%_m$ was the moisture content in the sample.

Densification of these materials was made using a hydraulic press with a 120mm long and 21mm diameter fixed die. It was fitted on a stainless steel base; the press plunger moves straight down with no lateral movement. Press force could vary between 113MPa and 200MPa. All samples were densified at the same pressure. The die has not any heating device; hence, all the solids were made at ambient conditions (18°C and 87.993kPa).

The characteristics analyzed for the solids were their dimensions, final bulk density and the compression ratio. The dimensions of the pellets were measured according to Obernberger and Thek (2004) by measuring the length and diameter of 20 randomly selected samples; thus, the ratio length/diameter were calculated. Based on the dimensions, it was possible to reckon the volume, thus final bulk density was defined as the ratio between green solids weight and volume. The average bulk density was calculated for ten measurement series per sample. Based on the fact that densification is a mechanical process, and no heat was added to the system final heating value, sulfur and nitrogen content were assumed constant and equal to initial values. Compression ratio was calculated as the relation between final and initial density (Equation 3).

$$CR = \frac{\rho_{fin}}{\rho_{in}} \qquad (3)$$

where CR was the compression ratio, ρ_{fin} ($kg \cdot m^{-3}$) was the final density and ρ_{in} ($kg \cdot m^{-3}$) was the density before densification.

$$HHV = 339 \cdot \%C + 1213 \left(\frac{\%H_2 - \%O_2}{8}\right) + 226 \cdot \%H_2 + 105 \cdot \%S \qquad (2)$$

$$HHV = 20490 - 271 \cdot \%ash_{db}$$

$$LHV = \frac{\dfrac{HHV\left(\dfrac{1 - \%_m}{100}\right) - 2.447 \cdot \%_m}{100} - \%H_2}{200} \cdot 18.02 \cdot 2.447 \left(\frac{1 - \%H_2}{100}\right)$$

Table 1. Important parameters of solid fuels classification in Sweden based on EN-14601.

Parameter	Test method	Unit	Group 1	Group 2	Group 3
Length	Measure 10 pellets	mm	Max 4·Φ	Max 5·Φ	Max 5·Φ
Bulk density	SS 187178	$kg{\cdot}m^{-3}$	>600	>500	>500
Durability	SS 187180	mass loss	0.8% <3mm	1.5% <3mm	1.5% <3mm
Low heating value	SS-ISO 1928	$MJ{\cdot}kg^{-1}$	>16.9	>16.9	>15.1
Ash	SS 187171	% $mass_{d.b.}$	<0.7	<1.5	<1.5
Moisture	SS 187170	% $mass_{w.b.}$	<10	<10	<12
Sulfur	SS 187177	% $mass_{d.b.}$	<0.08	<0.08	To be stated
Chlorides	SS 187185	% $mass_{d.b.}$	<0.03	<0.03	To be stated

Table 2. Parameters required for Pellet Gold.

Parameter	Unit	Limit
Moisture content	$\%mass_{w.b.}$	<10
Ash content	$\%mass_{d.b.}$	≤1
Mechanical durability	%	>97.7
Binding agents	%	<2%
Low heating value	$MJ{\cdot}kg^{-1}$	≥16.9
Nitrogen content	$\%mass_{d.b.}$	≤0.3
Chlorine content	$\%mass_{d.b.}$	<0.03
Sulfur content	$\%mass_{d.b.}$	<0.05
Lead content	$mg{\cdot}kg^{-1}$	<10
Mercury content	$mg{\cdot}kg^{-1}$	<0.05
Cadmium content	$mg{\cdot}kg^{-1}$	<0.5
Chromium content	$mg{\cdot}kg^{-1}$	<8
Formaldehyde	$mg{\cdot}100g^{-1}$	<1.5
Radioactivity	$Bq{\cdot}kg^{-1}$	<6

In order to evaluate the properties of the solids, they were compared with standard parameters employed in the most influential European markets, i.e. Sweden, Austria, Germany and Italy. The Swedish pellets Standard SS 18 71 20 was used since 1999; nowadays, European standard EN-14601 is used. This standard classifies solid biofuel pellets into three groups (IEA Bioenergy 2011); number one is designed to fit high quality systems, especially small scale boilers for residential and private usage. Groups 2 and 3 are defined to supply larger scale systems which do not require the highest quality.

In Germany and Austria, EN 14961-2 has replaced the existing standards, DIN 51731 and ÖNORM M7135. The

Table 3. Typical parameters for solid biofuel classification in Germany and Austria.

Parameter	Test method	Unit	ENplus-A1	ENplus-A2	EN-B
Diameter	To be stated	mm	6-8	6-8	6-8
Length	To be stated	mm	3.15-40.0	3.15-40.0	3.15-40.0
Bulk density	EN 15103	$kg \cdot m^{-3}$	≥600	≥600	≥600
Net calorific value	EN 14918	$MJ \cdot kg^{-1}$	16.5-19.0	16.3–19.0	16.0–19.0
Moisture content	EN 14774-1	$\%mass_{w.b.}$	≤10	≤10	≤10
Mechanical durability	EN 15210-1	$\%mass_{w.b.}$	≥97.5	≥97.5	≥96.5
Ash content	EN 14775	$\%mass_{w.b.}$	≤0.7	≤1.5	≤3.0
Ash melting behaviour	EN 15370-1	°C	≥1200	≥1100	≥1100
Chlorine content	EN 15289	$\%mass_{d.b.}$	≤0.02	≤0.02	≤0.03
Sulfur content	EN 15289	$\%mass_{d.b.}$	≤0.03	≤0.03	≤0.04
Nitrogen content	EN 15104	$\%mass_{d.b.}$	≤0.3	≤0.5	≤1.0
Copper content	EN 15297	$mg \cdot kg^{-1}$	≤10	≤10	≤10
Chromium content	EN 15297	$mg \cdot kg^{-1}$	≤10	≤10	≤10
Arsenic content	EN 15297	$mg \cdot kg^{-1}$	≤1	≤1	≤1
Cadmium content	EN 15297	$mg \cdot kg^{-1}$	≤0.5	≤0.5	≤0.5
Mercury content	EN 15297	$mg \cdot kg^{-1}$	≤0.1	≤0.1	≤0.1
Lead content	EN 15297	$mg \cdot kg^{-1}$	≤10	≤10	≤10
Nickel content	EN 15297	$mg \cdot kg^{-1}$	≤10	≤10	≤10
Zinc content	EN 15297	$mg \cdot kg^{-1}$	≤100	≤100	≤100

solid biofuel pellets are classified into three groups based on their characteristics; they are ENplus-A1, ENplus-A2 and EN-B. Some properties, of each group are in Table 1.

Most of the pellets used in Italy are for space heating in small-scale units; the Italian market employed the Pellet Gold label to guarantee adequate pellet characteristics. Some of the required properties that pellet needs to acquire this label are defined in Table 2. However, during the next years these requirements will change according to EN 14961 in the same manner as in Germany and Austria (Table 3).

RESULTS AND DISCUSSION

During raw material pretreatment, coconut shells present some problems due to their mechanical durability; the equipment required needs more power than that used for palm oil shells grinding. Initial density shows the importance for compressing some of these materials; the wood shavings had the lowest bulk density ($165.37 kg \cdot m^{-3}$) while coconut shells had the highest ($468.58 kg \cdot m^{-3}$) among examined samples. Nevertheless, these values were very low in comparison with typical ranges for coal ($650–800 kg \cdot m^{-3}$). This parameter is a fundamental

Table 4. Proximate analysis of employed raw materials in comparison to a Colombian hard coal sample.

Parameter	Unit	S.d.	W.sh.	C.sh.	P.o.sh.	D.c.
Density	kg·m^{-3}	200.59	165.37	468.58	197.86	650-800
Moisture	%mass$_{w.b.}$	9.67	12.14	12.01	7.92	2.75
Volatile matter	%mass$_{w.b.}$	76.82	76.21	71.45	72.74	37.73
Fixed carbon	%mass$_{w.b.}$	11.71	10.56	15.28	16.87	51.02
Ash content	%mass$_{w.b.}$	1.80	1.09	1.26	2.47	8.5

S.d. – saw dust
W.sh. – wood shavings
C.sh. – coconut shells
P.o.sh. – palm oil shells
D.c.- hard coal

Table 5. Ultimate analysis of sawdust (S.d.), wood shavings (W.sh.), coconut shells (C.sh.), palm oil shells (P.o.sh.) and hard coal (D.c.). All data expressed in %mass$_{d.b.}$

Parameter	S.d.	W.sh.	C.sh.	P.o.sh.	D.c.
Carbon	42.14	45.86	44.76	47.30	71.28
Oxygen	45.82	43.75	44.73	39.39	12.59
Hydrogen	9.07	9.07	8.92	9.72	5.27
Nitrogen	0.98	0.08	0.16	0.84	1.63
Sulfur	0.00	0.00	0.03	0.07	0.73
Ash	1.99	1.24	1.40	2.68	8.50

characteristic because it affects transportation costs, necessary space for storage and energy density.

Proximate analysis and ultimate analysis indicated the strong relation between some typical characteristics and the heating value and the potential of biomass for energy production. Coconut shells and wood shavings should be dried beforehand due to their high water content (12%), whereas sawdust and palm oil shells (>8%) could be used as received (although sawdust had a remarkably low density).

Volatile matter content and fixed carbon are parameters that affect the combustion process directly, among the examined materials, sawdust and wood shavings had more volatile compounds than coconut, palm oil shells or dark coal, but fixed carbon levels higher from the latter three. Sawdust and wood shavings will release more volatile material at the first stage of the combustion process; although, these materials will add energy for char combustion. Based on proximate analysis it is possible to comprehend the performance of the material during combustion. Thus, solids like coconut shells (C.sh.), palm oil shells (P.o.sh.) or hard coal (D.c.) will release more energy due to combustion, but will require more energy for reaction activation (Table 4).

On the same manner, the ultimate analysis supports this theory; the materials with high fixed carbon content have more elemental carbon. Nevertheless, there is a relevant relation between oxygen content and volatile matter. If coal results are compared against biomass analysis, it would be possible to establish the relationship between oxygen and carbon on the solid structure with volatiles content. For instance, coal volatile matter is low (12%) due to content of oxygen; whereas, biomass has volatiles around 75% due to higher oxygen content (approximately 43%) in the structure (Table 5).

Table 6. Experimental and calculated higher heating value expressed in $kJ \cdot kg^{-1}$.

Parameter	S.d.	W.sh.	C.sh.	P.o.sh.	D.c.
Experimental	20130	21055	21300	20160	32323
Calculated (Equation 1)	20393	21968	21234	24062	29919
Calculated (Equation 2)	19950	20154	20110	19763	18187
Low heating value	18181	18497	18740	18561	31433

S.d. – saw dust
W.sh. – wood shavings
C.sh. – coconut shells
P.o.sh. – palm oil shells
D.c.- hard coal

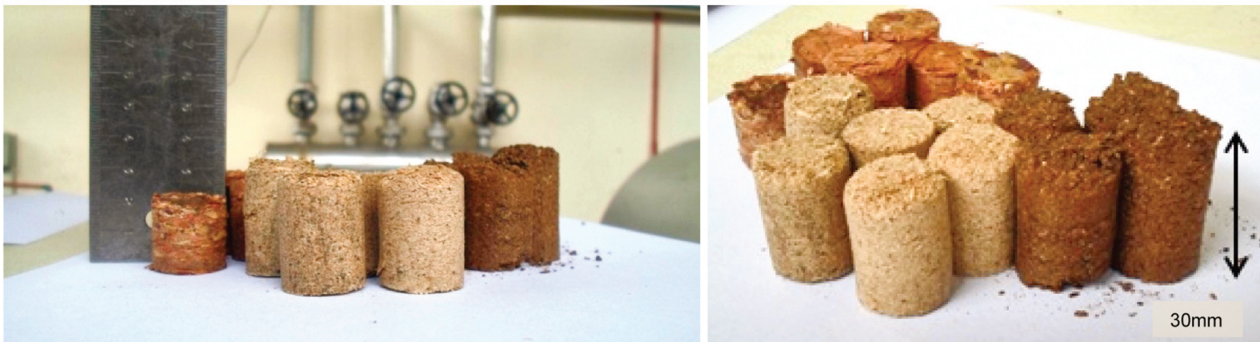

Figure 3. Pellets from sawdust, coconut shells and wood shavings made by pressing.

Table 7. Results obtained after densification.

Parameter	Unit	S.d.	W.sh.	C.sh.	P.o.sh.
Diameter	mm	21	21	21	21
Length	mm	32	22	38	24
Density	$kg \cdot m^{-3}$	1028	850	902.9	1023
Heating value	$kJ \cdot kg^{-1}$	17221	19425	18707	19944
Compression ratio	*	5.12	5.15	1.92	5.17

S.d. – saw dust
W.sh. – wood shavings
C.sh. – coconut shells
P.o.sh. – palm oil shells
* – undimensional

A key parameter that should be evaluated is the ash content. Low ash content prevents multiple problems in boilers and furnaces regarding the formation of fused solids and high emissions of particulate matter. Furthermore, there is another advantage of biomass. Low sulfur and nitrogen content mean less SO_x or NO_x produced in boilers and furnaces. Analysis of heating value confirms the relation between elemental analysis with energy released during combustion; coal with large elemental carbon and low oxygen has the highest HHV (32.3MJ·kg^{-1}); whereas, biomass HHV is similar for all these residues (approximately 20.1MJ·kg^{-1}), but 32% smaller.

Likewise, calculated higher heating values indicate that equations used and presented before are reliable for determining biomass heating values; however, this is not the case when coal heating value is considered (Table 6). This occurs because the Equation (2) is based on heating value of lignocellulose which is not a component of coal structure. Moisture content is also a factor that should be considered; the difference between lower and higher heating values indicate that energy lost due to moisture evaporation is around 10% for biomass, and no more than 3% for coals. Therefore, lower heating value should be employed during the design of household, boilers or any other biomass energy systems if a more reliable and real fuel consumption calculation is needed.

After densification, solids produced had the characteristics presented below, mean length of pellets was around 29mm and bulk density varied from 850kg·m^{-3} to 1028kg·m^{-3} (Table 7). Sawdust compression ratio was high (5.15) and final bulk density was over 1000kg·m^{-3}. The relation between initial and final density of coconut shells and its low compression ratio were in accordance with the problems reported during biomass pretreatment. Coconut has low plastic and elastic deformation during densification due to rigid chemical structure and solid strength, which make this material less suitable for pellets or briquettes production.

On the other hand, sawdust, wood shavings and oil palm shells have appropriate compression ratio, final density and heating value. Pellets produced with these Colombian materials could be distributed in Sweden and Italy based on European standards (Figure 3). To achieve requirements for Germany or Austria it is necessary to change the die used because dimensions are oversized; however, another study is required in order to establish the influence of dimensions on physical properties.

CONCLUSIONS

In Colombia, it is feasible to produce pellets or briquettes using timber and oil palm solid residues. These could fulfill European standard requirements; otherwise, the production of coconut shell pellets is not a suitable option due to its low compression ratio and its high mechanical resistance, which made the product final density lower.

Measurement of timber, palm oil solid residues and coconut shells main characteristics is necessary in order to establish the potential of these materials as energy sources for further processes such as combustion or gasification. Wood shavings, oil palm shells and sawdust require to be densified in order of increasing energy density; however, coconut shells should be used without prior densification.

The utilization of these kinds of materials for energy processes and indeed on co-firing systems generates a significant impact on the environment, based on low sulfur content and affordable heating values reported in this work. This will provide other alternatives for reducing problems caused by brown coal combustion in some areas of Colombia.

Massive production of fuel pellets from wood and other biomass for small and medium scale energy systems could give a positive development of rural areas in Colombia, where there is a lot of these resources and lack of stable electrical supply. Therefore, more research on different alternatives for biomass solid biofuel production, on analysis of their characteristics and their behavior on combustion or gasification processes, should be performed.

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