CHARACTERIZATION OF RESIDUES FROM PLANT BIOMASS FOR USE IN ENERGY GENERATION

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ABSTRACT: The use of plant residues for energy purposes is already a reality, yet in order to ensure suitability and recommend a given material as being a good energy generator, it is necessary to characterize the material through chemical analysis and determine its calorific value. This research aimed to analyze different residues from plant biomass, characterizing them as potential sources for energy production. For the accomplishment of this study, the following residues were used: wood processing residue (sawdust and planer shavings); coffee bean parchment and coffee plant stem; bean stem and pod; soybean stem and pod; rice husk; corn leaf, stem, straw and cob; and sugar cane straw and bagasse. For residue characterization the following analyses were done: chemical analysis, immediate chemical analysis, calorific value and elemental analysis. All procedures were conducted at the Laboratory of Forest Biomass Energy of the Federal University of Lavras. In general, all residues showed potential for energetic use. Rice husk was found to have higher lignin content, which is an interesting attribute as far as energy production is concerned. Its high ash content, however, led to a reduction in calorific value and fixed carbon. The remaining residues were found to have similar energetic characteristics, with corn cob showing greater calorific value, followed by coffee plant stem, both also containing higher levels of carbon and fixed carbon. A high correlation was found of higher calorific value with volatile materials, carbon and hydrogen contents.

Key words: Lignocellulosic residues, chemical analysis, calorific value, bioenergy.

CARACTERIZAÇÃO DE RESÍDUOS DE BIOMASSA VEGETAL PARA UTILIZAÇÃO ENERGÉTICA

RESUMO: A utilização de resíduos vegetais para fins energéticos já é uma realidade, porém, para afirmar e indicar um determinado material como bom gerador de energia, é necessário caracterizá-lo através de análises químicas e da determinação de seu valor calórico. Objetivou-se, com este trabalho, analisar diferentes resíduos de biomassa vegetal, caracterizando-os como potenciais para a produção de energia. Para a realização deste trabalho, foram utilizados os seguintes resíduos: resíduos do processamento da madeira (serragem e maravalha); pergaminho do grão e caule do cafeeiro; caule e vagem do feijão; caule e vagem da soja; casca de arroz; folha, caule, palha e sabugo de milho e palha e bagaço da cana-de-açúcar. Para a caracterização dos resíduos, foram realizadas as seguintes análises: análise química, análise química imediata, poder calorífico e análise elementar. Todas as análises foram conduzidas no Laboratório de Energia da Biomassa Florestal da Universidade Federal de Lavras. De forma geral, todos os resíduos apresentaram potencial para serem utilizados na produção de energia. A casca de arroz apresentou o maior teor de lignina, característica interessante para produção de energia. No entanto, o seu alto teor de cinza acarretou uma redução no poder calorífico e carbono fixo. Os demais resíduos apresentaram características semelhantes do ponto de vista energético, com destaque para o sabugo de milho, que apresentou maior poder calorífico, seguido do caule do café, ambos continham também maior quantidade de carbono e carbono fixo. O poder calorífico superior apresentou alta correlação com o teor de materiais voláteis, carbono e hidrogênio.

Palavras-chave: Resíduos lignocelulósicos, análise química, poder calorífico, bioenergia.

1 INTRODUCTION

Brazil is a leading forest and agricultural producer for a variety of reasons, including area availability for cultivation, possibility of introducing assorted cultures, geographic position favoring intense solar radiation throughout the year, tropical climate, besides its extremely rich biodiversity and advanced technology, all of which allow Brazil to hold a privileged position in the field of agrarian sciences.

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As a result, Brazil has become one of the world's largest producers of wood and agricultural products and is known by many as 'the barn of the world'. In spite of that, intensive production generates large amounts of residue and that can cause serious environmental problems.

According to Vale and Gentil (2008), residue can be defined as any discarded material from activities relating to a production process, being a potential hazard to the environment and, consequently, to society. By contrast, residues can go from being a hazardous risk to becoming generators of profit if they are turned into raw materials for other processes, reducing both the price and the demand for the main product.

Wood is an important input whose value has increased in past decades, yet it is not being used fully (RIBEIRO; ANDRADE, 2005). According to Lima and Silva (2005), every process involving wood transformation generates residues but only 40% to 60% of the total volume of logs harvested is actually used.

The processing of agricultural crops also generates large amounts of residue. According to Instituto Brasileiro de Geografia e Estatística - IBGE (2006), in 2006 alone Brazil produced around 11 million tons of bulk, unprocessed rice which in turn generated 2.6 million tons of rice husk. Rocha et al. (2006) argue that the ratio of processed coffee beans to residue can reach 50%. According to Macedo (2001), each ton of sugar cane (culm) produces 140 kg (dry matter) of bagasse, 150 kg of sugar and 140 kg (dry matter) of stubble, lost from field burns. According to Chagas et al. (2007), residue from bean crops includes straw and stalk, making up 60% (in weight) of the crop. Soybean is produced on a larger scale in Brazil and thus generates an equally larger amount of residue. According to Bose and Martins Filho (1984), soybean stubble corresponds to as much as 120% to 150% of soybean weight.

Lignocellulosic residue can be reused as raw material in a different process from the original process, for instance, it can be used energetically for generation of heat or electricity in generator groups or thermoelectric plants (QUIRINO, 2003).

According to Vale and Gentil (2008), biomass residues are solid fuels that can be used directly as they are, under moisture controlled conditions, and be transformed by mechanical processes into small particles such as wood chips or sawdust, or else pressed into briquettes.

The use of residues from plant biomass for energy purposes is already a reality. However, in order to ensure suitability and recommend a given material as being a good energy generator it is necessary to characterize the material through chemical analysis and determine its calorific value.

Thus the objective of this work is to analyze different lignocellulosic residues, characterizing them as potential sources for energy production.

2 MATERIAL AND METHODS

In order to conduct this study, lignocellulosic residues were obtained in the municipality of Lavras/MG, including wood processing residues (planer shavings and sawdust), coffee bean parchment and coffee plant stem, bean stem and pod, soybean stem and pod, rice husk, corn leaf, stem, straw and cob, plus sugar cane straw and bagasse. The residues were submitted to analysis at the Laboratory of Forest Biomass Energy of the Federal University of Lavras.

The material was ground by a Wiley blade apparatus, using the fraction that passed through a 40-mesh screen but was retained in a 60-mesh screen. The residues were stored under controlled temperature (20 ± 3)°C and relative humidity (65 ± 2)% for moisture homogenization.

An elemental analysis was performed to start with for determination of carbon, hydrogen, nitrogen, sulfur and, by difference, oxygen contents of the material. For that, approximately 2 mg of residue was weighed in a tin sample holder. The aggregate (residue + sample holder) was then placed in the *carousel* of an Elementar® *elemental analyzer*. The analysis was performed on one sample at a time. The gases necessary for the operation included helium, used as carrier gas, and oxygen, used as ignition gas. The temperature of the combustion tube, which is located inside the equipment, at the moment the sample was fed into the carousel was 1,150 °C. After combustion, gases were stripped to the reduction tube and then to the detection column. Elements were determined by a thermal conductivity detector whereby each element interacted and had its specific peak. The computer coupled to the equipment made the relevant calculations and derived values expressed as percentage.

The determination of silicon content in rice husk was done using the molybdenum colorimetric method, according to Furlani and Gallo (1978).

The chemical analysis followed Standards M3/89, M11/77 and M70/71 of Associação Brasileira Técnica de Celulose e Papel - ABTCP (1974), for determination of extractives content, ash content and lignin content respectively. The holocellulose content (H) was done on the basis of Equation 1, using percentage in relation to dry matter of components.

$$H(\%) = 100 - ET(\%) - LI(\%) - CI(\%) \qquad (1)$$

where:
ET = extractives total;
LI = lignin;
CI = ash.

The immediate chemical analysis was based on Standard 8112 of Associação Brasileira de Normas Técnicas - ABNT (1983), to determine volatile materials and ash content. Fixed carbon content (CF) was derived from the difference (Equation 2).

$$CF(\%) = 100 - MV(\%) - CI(\%) \qquad (2)$$

where:
MV = volatile materials;
CI = ash.

The analysis for determination of higher calorific value was performed in a Parr® calorimeter, following standard 8633, ABNT (1984). Determination of lower calorific value (PCI) was based on Equation 3.

$$PCI = PCS - 5.72*(9H + U) \qquad (3)$$

where:
PCS = higher calorific value;
H = Hydrogen (%);
U = Moisture (%).

An analysis of correlation was performed to verify associations between the characteristics being analyzed.

3 RESULTS AND DISCUSSION

Table 1 provides elemental analysis results for residues.

In analyzing Table 1 it is noted that the sulfur content was low for all residues, ranging from 0.1% to 0.4%. The presence of sulfur in fuels is undesirable due to erosion problems and release of SO_2 gas after combustion.

Table 2 provides reference values for the elemental analysis of some residues.

Table 1 – Elemental analysis of residues.

Tabela 1 – Análise elementar dos resíduos avaliados.

Material		Elements (%)						
		C	H	N	S	O	C/H	C/N
Rice	Grain husk	39,1	5.8	0.3	0.1	54.7	6.7	130.3
Coffee	Plant stem	48.6	6.8	0.5	0.1	44.0	7.2	97.0
	Bean parchment	47.2	6.9	0.5	0.2	45.1	6.8	94.4
Sugar cane	Bagasse	45.3	6.8	0.5	0.3	47.1	6.7	90.6
	Straw	44.6	6.6	0.3	0.4	48.1	6.8	148.7
Bean	Stem	44.3	6.6	0.7	0.3	48.1	6.7	63.3
	Pod	41.8	6.5	0.9	0.3	50.5	6.4	46.4
Wood	Sawdust	48.2	6.5	0.1	0.2	45.1	7.4	482.0
	Planer shavings	47.3	6.6	0.1	0.2	45.8	7.2	473.0
Corn	Stem	45.6	6.5	0.9	0.3	46.8	7.0	50.7
	Leaf	45.4	6.8	0.9	0.3	46.5	6.7	50.4
	Straw	44.8	6.8	0.3	0.1	47.9	6.6	149.3
	Cob	45.5	6.7	0.5	0.3	47.0	6.8	91.0
Soybean	Stem	45.7	6.6	0.6	0.1	47.0	6.9	76.2
	Pod	42.5	6.5	1.6	0.3	49.0	6.5	26.6

Table 2 – Reference values for elemental analysis.

Tabela 2 – Valores de referência para a análise elementar.

Material		Elemental analysis (%)					Reference
		C	H	N	S	O	
Rice	Grain husk	40.96	4.30	0.40	0.02	-	Jenkins (1990)
Coffee	Bean parchment	44.00	5.40	0.70	-	49.90	Brum et al. (2008)
Sugar cane	Bagasse	46.70	5.90	0.90	-	46.50	Seye et al. (2003)
	Straw	43.42	5.71	1.23	-	49.64	
Bean	Straw	41.50	5.90	0.60	-	52.00	Oliveira (2009)
Wood	Residue	48.06	6.03	0.70	-	45.21	Seye et al. (2003)
Corn	Stem + Leaf	41.90	5.30	0.00	-	46.00	Raveendran et al. (1995)
	Cob	47.60	5.00	0.00	-	44.60	
	Straw	45.80	4.50	0.75	-	48.90	Bianchi (1995)

Rice husk had higher oxygen content and lower carbon and hydrogen contents, being in agreement with Jenkins (1990).

Elemental analysis results for coffee plant stem and coffee bean parchment were similar to results for wood residues, except nitrogen content, found higher in coffee residues. Lower nitrogen content in wood residues resulted in a high C/N ratio. Analysis values for coffee bean parchment are in agreement with Brum et al. (2008).

Sugar cane bagasse and straw, as well as wood residues, showed similar results to those by Seye et al. (2003).

The elemental analysis of bean straw (stem + pod), as conducted by Oliveira (2009), provided similar results to results found in this study.

The percentages of corn stem and leaf elements are in agreement with Raveendran et al. (1995), who also studied corn plant (stem + leaf). Results for corn cob and straw were similar to the literature result in Table 2.

A higher C/N ratio was observed for sawdust, as shown in Table 1, followed by planer shavings, both of which being wood residues. According to Munalula and Meincken (2009) the higher nitrogen content is related to environmental impacts and air pollution as a function of the formation of toxic nitrogen oxides and nitric acid.

Table 3 provides average values of total extractives, lignin, ash and holocellulose contents found in the residues being assessed. Rice husk was found to have lower extractives content and higher ash content, in comparison with other residues. The high ash content is associated with a large amount of silica (SiO_2); the analysis detected 8.32% of silica. The lignin content obtained by

Reyes et al. (1997) for rice husk was similar to findings in this research, unlike ash content. Additionally, rice husk showed a low holocellulose content, in association with its high ash content.

The reference values for these analyses are provided in Table 4. The result found for ash content in coffee plant stem is close to the result found by Pereira (2008), and bean parchment values were found similar to those in literature.

The extractives content found in cane bagasse differed from the finding of Pitarelo (2007), possibly because in his experiment the sugar cane originating the bagasse was burned and washed prior to being ground. The lignin content was similar to the value found by Marabezi et al. (2009).

The chemical analysis of bean residues (Table 3) provided differing component percentages for stem and pod; the broadest difference found was in extractives and lignin contents. From Table 4 it is noted that prior studies consider the aggregate straw (stem + pod) for analysis.

As for the chemical analysis of planer shavings and sawdust, no significant difference was found, and values are in agreement with results found by Mori et al. (2002) and Trugilho et al. (2003).

The chemical analysis of corn stem and leaf provided similar results, the same occurring for straw and cob, except the lignin content for the latter two.

The chemical analysis of soybean residues, stem and pod, provided differing values. The ash content of pod is in agreement with Silva et al. (2008). The values found for soybean were not very dissimilar to bean values, though that was expected as both belong to the pulse family.

Table 3 – Chemical analysis of residues.

Tabela 3 – Análise química dos resíduos avaliados.

Material		Extractives (%)	Lignin (%)	Ash (%)	Holocellulose (%)
Rice	Grain husk	4.06	26.90*	16.43	52.61
Coffee	Plant stem	10.49	22.88	1.12	65.51
	Bean parchment	7.63	23.04	1.46	67.87
Sugar cane	Bagasse	31.76	20.88	0.80	46.56
	Straw	9.18	20.85	4.32	65.65
Bean	Stem	7.55	21.61	4.61	66.23
	Pod	18.19	11.99	6.65	63.17
Wood	Sawdust	9.37	21.88	0.18	68.57
	Planer shavings	5.60	20.62	0.13	73.65
Corn	Stem	11.31	20.49	3.43	64.77
	Leaf	10.51	19.26	3.53	66.70
	Straw	5.85	9.29	1.58	83.28
	Cob	5.85	15.75	1.16	77.24
Soybean	Stem	6.87	21.64	2.28	69.21
	Pod	21.77	17.16	7.25	53.82

* Adjusted value, deducting 8.32% of silicon.

Table 4 – Reference values for chemical analysis.

Tabela 4 – Valores de referência para análise química.

Material		Chemical analysis (%)				Reference
		Extr.	Lign.	Ash	Hol.	
Rice	Grain husk	-	29.40	8.50	-	Reyes et al. (1997)
Coffee	Plant stem	-	-	0.68	-	Pereira (2008)
	Bean parchment	7.00	20.00	1.37	76.00	Brum (2007)
		-	24.50	0.50	66.20	Brahan and Bressani (1978)
Sugar cane	Bagasse	6.80	30.00	2.40	-	Pitarelo (2007)
		-	19.25	-	-	Marabezi et al. (2009)
	Straw	11.5	39.70	11.70	-	Pitarelo (2007)
		-	19.10	-	-	Marabezi et al. (2009)
Bean	Pod+Straw	22.7	8.40	-	71.70	Brum et al. (2006)
		-	-	4.30	-	Oliveira (2009)
Wood	*E. grandis* *E. saligna*	6.71	31.77	0.17	61.52	Trugilho et al. (2003)
	E. urophylla	9.15	26.70	0.16	63.62	Mori et al. (2002)
Corn	Leaf	-	12.60	-	72.00	Cruz et al. (2000)
	Cob	-	20.30	-	66.40	
	Straw	-	8.79	1.52	57.49	Salazar et al. (2005)
Soybean	Pod	-	-	8.90	-	Silva et al. (2008)

Extr., Lign., Ash, Hol. = Extractives, lignin, ash and holocellulose contents.

Results of immediate analysis and higher calorific value of residues are provided in Table 5. Table 6 contains reference values for these analyses.

The immediate analysis and calorific value of rice husk are in agreement with Diniz et al. (2004), Jenkins (1990) and Souza et al. (2005).

Table 5 – Immediate analysis and calorific value of residues.

Tabela 5 – Análise imediata e poder calorífico dos resíduos avaliados.

Material		Immediate analysis (%)		Calorific value (cal/g)	
		Volatile Materials	Fixed Carbon	Higher	Lower
Rice	Grain husk	66.36	17.30	3812.30	3445.08
Coffee	Plant stem	80.39	19.33	4544.00	4125.30
	Bean parchment	79.14	19.90	4441.74	4017.89
Sugar cane	Bagasse	82.31	17.16	4274.48	3855.78
	Straw	78.64	17.46	4315.66	3907.25
Bean	Stem	77.53	18.75	4488.74	4080.33
	Pod	76.65	18.10	4218.53	3815.27
Wood	Planer shavings	83.19	16.66	4291.71	3888.45
	Sawdust	78.89	21.03	4435.04	4026.63
Corn	Stem	76.82	20.47	4211.88	3808.62
	Leaf	78.30	18.43	4464.52	4045.82
	Straw	81.68	17.05	4443.38	4024.68
	Cob	81.31	18.32	4615.26	4201.70
Soybean	Stem	80.59	18.06	4504.25	4095.84
	Pod	76.61	18.24	4028.54	3625.28

Table 6 – Reference values for immediate analysis and calorific value.

Tabela 6 – Valores de referência para análise imediata e poder calorífico.

Material		Immediate Analysis		PCal (cal/g)	Reference
		Volatile Materials (%)	Fixed Carbon (%)		
Rice	Grain husk	64.30	11.90	-	Souza et al. (2005)
		65.47	16.67	3852.00	Jenkins (1990)
		-	-	3908.00	Diniz et al. (2004)
Sugar cane	Bagasse	73.78	14.95	4139.00	Jenkins (1990)
		69.39	16.10	-	Seye et al. (2003)
	Straw	66.40	16.35	-	
Wood	*Eucalyptus*	74.10 to 89.90	9.60 to 24.30	-	Brito and Barrichello (1978)
	Dry wood	-	-	4000 to 4800	Brito (1993)
Corn	Stem + leaf	80.10	13.10	3956.94	Raveendran et al. (1995)
	Cob	85.40	11.80	3744.02	
		80.10	18.54	4498.00	Jenkins (1990)
	Straw	-	-	3730.00	Quirino et al. (2005)
Soybean	Pod	63.50	27.70	-	Silva et al. (2008)

The immediate analysis of coffee plant stem and coffee bean parchment provided similar results to wood results.

The values determined in this study for sugar cane bagasse are in agreement with Jenkins (1990) and Seye et al. (2003), except volatile materials content.

Sugar cane straw was found to have similar fixed carbon value and calorific value to bagasse. Seye et al. (2003) observed lower fixed carbon contents than this study.

The immediate analysis results for bean residues, stem and pod, provided similar values of volatile materials and fixed carbon. The calorific value of the stem was slightly higher, possibly due to its higher lignin content.

The calorific value of wood residues is within the range determined by Brito (1993) and Brito and Barrichello (1978), as provided in Table 6.

The immediate analysis of corn stem and leaf provided similar results of volatile materials to values found by Raveendran et al. (1995), who studied corn plant as an aggregate, in other words, stem plus leaf. The volatile materials content in corn cob was similar to literature results, unlike ash content and calorific value. The immediate analysis and calorific value of corn cob are in agreement with Jenkins (1990). Quirino et al. (2005) observed an inferior calorific value for cob straw.

Results for soybean residues proved similar to results for bean residues. Silva et al. (2008) observed a higher fixed carbon value for soybean pod than this study did.

The lower calorific value is within the expected range for lignocellulosic materials. Corn cob provided the highest value and rice husk, the lowest.

In observing results of residue analyses, dissimilarity is observed, in most cases, in relation to literature results. According to Brum (2007), it should be taken into account that the chemical constitution of materials is conditional on several factors, including soil composition, climate, harvest season, disease and weed presence, planting method, among others, all of which can cause even plants of the same species to differ in composition. Differences may also occur in the way the material is sampled and in the analysis methodology. Additionally, by their very nature, residues are remainders of other processes and thus may well be contaminated or stored unsuitably.

The most significant coefficients of correlation for the characteristics being assessed in residues are provided in Table 7.

Table 7 – Main coefficients of correlation between assessed characteristics.

Tabela 7 – Principais coeficientes de correlação entre as características avaliadas nos resíduos.

Variables	Correlation
Extractives – Holocellulose	-0.6937
Ash – Volatile materials	-0.9550
Ash – Higher calorific value	-0.8052
Ash – Carbon	-0.9045
Ash – Hydrogen	-0.8387
Ash – Oxygen	0.9212
Holocellulose – Higher calorific value	0.6567
Volatile materials – Higher calorific value	0.7525
Volatile materials – Carbon	0.7782
Volatile materials – Hydrogen	0.8464
Volatile materials – Oxygen	-0.8106
Higher calorific value – Carbon	0.7547
Higher calorific value – Hydrogen	0.7604
Higher calorific value – Oxygen	-0.7643
Carbon – Hydrogen	0.7140
Carbon – Oxygen	-0.9793
Hydrogen – Oxygen	-0.8076
Nitrogen – C/N ratio	-0.7056
Carbon – C/H ratio	0.6704
C/H ratio – C/N ratio	0.7263

A high positive correlation was found of higher calorific value with volatile materials, carbon and hydrogen contents, and a high negative correlation was found of higher calorific value with oxygen content.

A high correlation was expected of lignin, extractives and fixed carbon contents with higher calorific value, despite results. This is possibly due to the great variability in residues used in this study. Holocellulose content, however, was found to have a moderate, positive correlation with higher calorific value.

4 CONCLUSIONS

In general, all residues showed good potential for use in energy generation. In the elemental analysis, the carbon content varied within the range expected for lignocellulosic materials, except for rice husk. This latter residue showed higher lignin content, but also high ash and oxygen contents and low carbon content,

which probably led to a reduction in calorific value and fixed carbon content. The remaining residues showed similar characteristics, with special mention of corn cob which showed greater calorific value, followed by coffee plant stem. All residues showed high levels of volatile materials and low levels of fixed carbon. Higher calorific value had a high positive correlation with volatile materials, carbon and hydrogen contents, and a negative correlation with oxygen content. An alternative way of improving the energetic properties of residues, reducing the level of volatile materials and increasing the calorific value, is applying torrefaction to residues or blending them with fine charcoal particles.

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