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Production and evaluation of briquettes from urban pruning residue and sugarcane bagasse

Ana K. de G. Smith[1], Letícia S. Alesi[1], Luciano D. Varanda[1], Diego A. da Silva[1], Luis R. O. Santos[1] & Fábio M. Yamaji[1]

[1] Universidade Federal de São Carlos/Departamento de Ciências Ambientais/Programa de Pós-Graduação em Planejamento e Uso de Recursos Renováveis. Sorocaba, SP. E-mail: kathegodoysmith@gmail.com – ORCID: 0000-0003-2896-7259; le_alesi1@hotmail.com – ORCID: 0000-0001-6364-3028; lu.varanda@hotmail.com (Corresponding author) – ORCID: 0000-0003-1193-4944; diegoaleixo.florestal@gmail.com – ORCID: 0000-0002-2552-7672; lrtatui@gmail.com – ORCID: 0000-0003-4649-7852; fmyamaji@ufscar.br – ORCID: 0000-0002-0908-8163

ABSTRACT: The search for new alternatives in order to reuse residues is one way to minimize environmental impacts by promoting sustainable practices. This study analyzed the technical feasibility of briquettes production from urban pruning residue and sugarcane bagasse, turning them into a product with higher added value besides directing their use and reducing their improper disposal. Five treatments were studied from different ratios of the two residues: T1, T2, T3, T4 and T5, respectively made of 100% of urban pruning; 50% urban pruning and 50% sugarcane bagasse; 25% urban pruning and 75% sugarcane bagasse; 10% urban pruning and 90% sugarcane bagasse; 100% sugarcane bagasse. The materials were characterized physically, chemically and energetically. Briquettes were produced and evaluated for mechanical performance, with expansion tests, mechanical resistance and friability to verify the quality of the final product. The treatments 1 and 2 showed the best results, with lower friability and average values of mechanical resistance of 167.14 and 107.56 kgf, respectively. It is concluded that both residues (sugarcane bagasse and urban pruning) had potential for briquette production, as well as the mixture between both materials.

Key words: bioenergy, biomass, reusing waste

Produção e avaliação de briquetes a partir de resíduos de poda urbana e bagaço de cana-de-açúcar

RESUMO: A busca de novas alternativas para reutilizar resíduos é uma maneira de minimizar impactos ambientais promovendo práticas sustentáveis. Este trabalho analisou a viabilidade técnica da produção de briquetes a partir de resíduos de poda urbana e bagaço de cana-de-açúcar, transformando-os em um produto com maior valor agregado, além de direcionar seu uso e reduzir a disposição inadequada. Foram estudados cinco tratamentos a partir de diferentes proporções dos dois resíduos: sendo T1, T2, T3, T4 e T5, respectivamente, 100% de resíduo de poda urbana; 50% de resíduo de poda urbana e 50% de bagaço de cana; 24% de resíduo de poda urbana e 75% de bagaço de cana; 10% de resíduo de poda urbana e 90% de bagaço de cana; e 100% de bagaço de cana. Os materiais foram caracterizados física, química e energeticamente. Foram produzidos briquetes e avaliados quanto ao desempenho mecânico, com testes de expansão, resistência mecânica e friabilidade para verificar a qualidade do produto final. Os tratamentos 1 e 2 apresentaram os melhores resultados, com menor friabilidade e valor médio de resistência mecânica de 167,14 e 107,56 kgf, respectivamente. Conclui-se que ambos os resíduos (bagaço de cana e poda urbana) apresentaram potencial para produção de briquete, bem como a mistura entre os dois materiais.

Palavras-chave: bioenergia, biomassa, reutilização de resíduos

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Introduction

Currently, concerns about non-renewable energy sources such as oil and coal are remarkably large. The study of alternatives for clean energy production such as the rational use of biomass is a great way to reduce the use of fossil fuels and the emission of greenhouse gases (Sette Junior et al., 2016; Souza & Vale, 2016; Tavares et al., 2016).

Due to its climate and soil advantages, Brazil has a superior development in agricultural and forest crops; thus, the residues coming from those activities are produced in a very large amount. According to the Sugarcane Industry Union (UNICA, 2017), the State of São Paulo was responsible for 56.1% of the national sugarcane production during 2016/2017, corresponding a total volume of 366 million tons. With each processed ton, 320 kilos of sugarcane bagasse are predicted to be generated (UNICA, 2017).

When urban conditions are analyzed, urban residues raise attention for their amount, which continues to grow, and for their deficit of suitable environmental solutions for their proper disposal or reuse. According to the Urban Solid Residues State Report by the Environmental Agency of the State of São Paulo (CETESB, 2016), the production of residues was approximately 43000 t d^{-1} in São Paulo, with 860 tons being rejected as trash containing pruning residues from urban trees. According to Meira (2010), there are no references regarding the quantification of urban pruning wastes but the amount is very large and is often directed to landfills where they lose their utility.

Since the Brazilian Act 12.305 of 2010, which established the National Policy of Solid Wastes (PRNS), the disposal in landfills of all kinds of residues, capable of being reused or recycled, has been forbidden. The final disposal must include combustion and other treatments by using technological processes, such as composting and energy reuse, improving the recovery of the system. With this scenario, the main problem is related to the large amount of waste generated and also to the environmental issue when its destination is not adequate.

Among the possible ways of using waste for energy production, briquetting is an interesting one, by applying pressure on a mass of particles, such as biomass wastes, it can form solid and compact blocks with high density (Li & Liu, 2000). The advantages of this method are easy transport and storage, uniform and good burning, and higher heat content (Stolarski et al., 2013).

This study aimed to evaluate the technical feasibility of briquettes produced by residues from urban pruning, sugarcane processing (bagasse), and a mix of both in different percentages.

Material and Methods

The materials used were urban pruning residues, collected in São Paulo, and sugarcane bagasse (first generation), provided by the sugar and ethanol plant, Usina Santa Rosa, in Porto Feliz, São Paulo, Brazil. The residues were stored in sealed plastic bags, in order to preserve their physical conditions until the analyses were done. In the urban pruning residue, species were not identified. The initial moisture contents were 71% in the urban pruning residue and 13% in the bagasse. They were not in contact with the ground and were protected by a canvas.

The bulk density of the residues was determined in accordance to ABNT NBR 6922 (ABNT, 1981) standard. The bulk density of the residues was determined in their initial moisture condition in triplicate.

The proximate analysis of the residues was performed in accordance to ABNT NBR 8112 (ABNT, 1986) standard. Moisture content and the volatile matter of each material was based on ABNT NBR 8112 (ABNT, 1986) standard. For the ash content analysis, TAPPI T211 (TAPPI, 1993) standard was used. Fixed carbon content was calculated in accordance to ABNT NBR 8112 (ABNT, 1986) standard, subtracting the sum between volatile and ash contents. The values were obtained in triplicate.

To obtain the organic solvent content (cyclohexane/ethanol) (1:1), TAPPI T204 (TAPPI, 1997) standard was used. In order to determine extractives soluble in hot water, a 1000 mL beaker with distilled water was used, based on TAPPI T212 (TAPPI, 1998) standard. The values were obtained in triplicate.

The Klason lignin content was determined in accordance to TAPPI T222 (TAPPI, 1988) standard. The values were obtained in triplicate.

The high heating value of materials (HHV) was determined in triplicate, with approximately 0.5 g of the residues of dry sample, by using a self-contained 'oxygen bomb' calorimeter model C500, from IKA. The same procedure was performed after the output of extractives in cyclohexane/ethanol and in hot water.

Different percentages of the selected biomasses provided a division of five treatments: T1, T2, T3, T4 and T5, respectively made of 100% of urban pruning; 50% urban pruning and 50% sugarcane bagasse; 25% urban pruning and 75% sugarcane bagasse; 10% urban pruning and 90% sugarcane bagasse; 100% sugarcane bagasse. The mixed material of each treatment totalized 300 g, which was adjusted to a 12% moisture content, and then, stored inside a sealed plastic bag until compaction.

Briquettes manufacture was accomplished with a Marcon model hydraulic press, at 1250 kgf cm^{-2} (122.5 MPa), for a period of 30 s. A 35-mm-internal-diameter cylindrical mold was used with 20 g of material for each sample. This procedure was accomplished without any type of heating sources or binders.

Samples were weighed on an analytical balance and measured with a digital caliper, 120 h after compaction. Apparent density was established by the quotient of the mass and volume of each briquette.

Height and diameter expansion was measured with a digital caliper at the following time intervals: immediately after compaction, 1, 3 and 8 h after compaction as well as prior to the tensile strength test by diametral compression.

Tensile strength test by diametral compression identified the maximum strength to which briquettes can be subjected until rupture occurs in their structure. This test was performed employing the universal test machine EMIC DL30000N, 120 h after briquetting. The force was applied perpendicularly to the compaction pressure. Twelve samples were used in the test for each treatment.

This test was based on ABNT NBR 8740 (ABNT, 1985) standard.

Reference values for the briquetting friability classification are: extremely friable (loss > 30%), averagely friable (loss between 20 to 30%), somewhat friable (loss between 10 to 19%) and slightly friable (loss < 10%).

Apparent density, mechanical resistance and pre-briquetting moisture content results were subjected to an analysis of variance, while the comparison between tests was conducted to a 0.05 significance level by F test. When null hypothesis was rejected, means were also compared to a 0.05 significance level, through Tukey test. For bulk density, proximate analysis and heating value, mean, variance and side deviation analysis were made. Statistical analyses were run with R 3.0.1. and Microsoft Excel software.

Results and Discussion

The bulk density results for both materials in their initial conditions are shown on Table 1.

Sugarcane bagasse had inferior bulk density when compared to urban pruning. The lower the bulk density the greater its volume, consequently there is a greater amount of available material for transporting and storing.

According to Vale et al. (2017), sawdust in general has bulk density varying from 100 to 300 kg m^{-3}. It can be affirmed that the obtained value in urban pruning fits these standards, given the fact that the material is a result of several wood species planted as city trees.

Table 2 presents the proximate analysis, extractives and Klason lignin contents, and heating value results for urban pruning residues and sugarcane bagasse.

Table 1. Bulk density of the residues

Material	M* (%d.b.*)	Bulk density (kg m^{-3})
Urban pruning	71 (0.10)	117.90 (5.75)
Sugarcane bagasse	13 (0.10)	85.93 (5.43)

*M - Moisture; d.b - Dry basis; standard deviation in parenthesis

Table 2. Proximate analysis, extractives and Klason lignin contents and heating value of the residues

Proximate analysis				
Material	Initial moisture	Ashes	Volatile matter	Fixed carbon
	(%)			
Urban pruning	71.00 (0.10)	9.57 (0.96)	74.73 (1.40)	16.69 (2.02)
Sugarcane bagasse	13.00 (0.10)	2.61 (0.57)	84.00 (0.36)	13.39 (0.69)
Extractives contents				
	Hot water soluble mean	Cyclohexane/ ethanol mean	Total	
	(%)			
Urban pruning	10.08 (0.31)	2.11 (0.14)	12.19 (0.31)	
Sugarcane bagasse	9.51 (0.55)	2.00 (0.10)	11.51 (0.50)	
Klason lignin contents				
	Klason lignin content (%)			
Urban pruning	30.82			
Sugarcane bagasse	22.11			
Heating value				
	HHV*	HHV EXT C/E*	HHV EXT H_2O*	
	(kcal kg^{-1})			
Urban pruning	4702.63	4291.34	4152.82	
Sugarcane bagasse	4410.26	4722.46	5018.75	

*HHV - High heating value; HHV EXT C/E - High heating value with extractives removed with Cyclohexane/ethanol; HHV EXT H_2O - Higher heating value with extractives removed with water; standard deviation in parenthesis

Nakashima et al. (2014) found a percentage of 84.03 for the content of volatile matter of sugarcane bagasse, close to that found in this study (84%). High volatile matter content provides an accelerated burning process, because the gases are emitted quickly in larger units of burning area. A successful alternative for materials with high volatile matter content, such as sugarcane bagasse, is the compaction, since this process reduces the superficial area and provides greater densification of residues, slowing down the burning rate of a fuel.

According to Santos et al. (2011), the ashes content is the fraction that remains as a residue after combustion of the material in solid state, the fixed carbon. A good solid fuel must have ashes content inferior to 3%. Sugarcane bagasse ashes (2.61) fell into the desired result. The analyzed urban pruning material showed a high value of ashes content (9.57%), which can be explained by the large quantity of contaminants, such as dirt, dust and sand, probably mixed with the material when collected. High ashes content may be disadvantageous, since it can form solid residues incrusted in the furnace's burners.

A lot of the energy content of the material is expressed in the form of fixed carbon, related to the energy and thermal resistance of the fuel, promoting a slower burning (Santos et al., 2011). The result found for urban pruning (16.69%) is plausible compared with that of the eucalyptus wood studied by Silva et al. (2015), which was 17.9%. The result obtained for sugarcane bagasse was 13.39%, which is comparable to the value of 12.87% obtained by Brasil et al. (2015).

The value of total extractives for bagasse (11.51%) is superior to the value 6.1% obtained by Gouveia et al. (2009). According to Moutinho et al. (2016), high extractives and lignin contents tend to increase the calorific value, a positive characteristic for energy production.

Lignin is a major contributor to the energy potential of solid biofuels due to its high carbon content composition, providing greater thermal resistance and delaying its decomposition (Gani & Naruse, 2007). Urban pruning residue exhibited higher heating value than sugarcane bagasse (Table 2).

Heating value is an excellent parameter to assess the energy potential of biomass fuels (Protássio et al., 2011).

The high heating value (HHV) obtained for urban pruning biomass (4702.63 kcal kg^{-1}) is higher than the HHV found in the study of *Eucalyptus grandis* sawdust performed by Gonçalves et al. (2013), which was 4229 kcal kg^{-1}.

According to Munalula & Meincken (2009), the heating value increases with the carbon content. Urban pruning residue showed greater fixed carbon content (Table 2), which also had superior HHV value when compared to sugarcane bagasse.

Table 3 shows the percentage of residues for each treatment, as well as the adjusted moisture content for compaction.

Table 3. Treatments and adjusted moisture content prior to compaction

Treatment	Urban pruning	Sugarcane bagasse	Moisture content
	(%)		(%d.b.*)
T1	100	0	11.9 (0.47)
T2	50	50	12.1 (0.20)
T3	25	75	12.2 (0.67)
T4	10	90	11.8 (0.25)
T5	0	100	12.3 (0.17)

T1 - 100% of urban pruning; T2 - 50% urban pruning and 50% sugarcane bagasse; T3 - 25% urban pruning and 75% sugarcane bagasse; T4 - 10% urban pruning and 90% sugarcane bagasse; T5 - 100% sugarcane bagasse; *d.b. - Dry basis; Standard deviation in parenthesis

For all treatments, the moisture content was very close, ranging from 11.8 to 12.3%. This moisture content is suitable for the production of briquettes (10 to 12%).

Table 4 presents mean apparent density of briquettes for each treatment.

The apparent density values were similar to those obtained by Gonçalves et al. (2013) for briquettes of *Eucalyptus grandis* sawdust. Quirino et al. (2012) performed a study of the apparent density of briquettes produced with residues of *Eucalyptus* sp. and obtained values between 1132 and 1343 kg m^{-3}, higher than the values of this study.

Treatment T1 showed greater apparent density. The lower the percentage of urban pruning residue the lower the apparent density. All treatments differed between one another in this analysis, except for T3 and T4.

The processing of residues (bulk density) in briquettes (apparent density) favors stocking and transporting, since material compaction causes better use of space and decrease of volume. Urban pruning residue volume suffered a reduction of 864% and sugarcane bagasse of 1567%.

Figure 1A shows that T5 exhibited the maximum diametric expansion, around 1%. Figure 1B shows the height expansion of briquettes, with T5 being the treatment with the maximum expansion of approximately 8%. The objective of Figure 1 was to present the behavior of the briquetting expansion curve, showing the period in which the expansion stabilized.

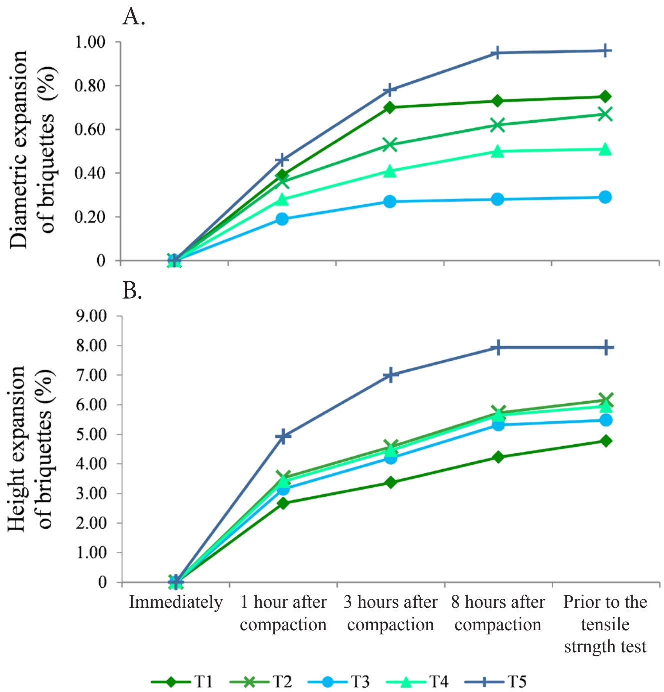
Yamaji et al. (2013) studied hygroscopicity of different biomasses and sugarcane bagasse showed one of the highest values in height expansion, demonstrating larger interference on the moisture content of briquettes. In addition to moisture absorption, expansion occurs due to the poor particle aggregation of the material. The same behavior was observed for sugarcane bagasse in this study.

Table 5 shows tensile strength and briquettes friability tests for five treatments.

Table 4. Mean apparent density of briquettes

Treatment	Mean apparent density (kg m^{-3})	Standard deviation
T1	1018.90 d	31.65
T2	968.96 c	11.46
T3	915.94 b	10.03
T4	903.85 b	9.97
T5	845.58 a	51.72

T1 - 100% of urban pruning; T2 - 50% urban pruning and 50% sugarcane bagasse; T3 - 25% urban pruning and 75% sugarcane bagasse; T4 - 10% urban pruning and 90% sugarcane bagasse; T5 - 100% sugarcane bagasse; Equal lowercase letters in the columns imply treatments with equivalent means, that is, that do not differ between them, at a 0.05 significance level



*T1 - 100% of urban pruning; T2 - 50% urban pruning and 50% sugarcane bagasse; T3 - 25% urban pruning and 75% sugarcane bagasse; T4 - 10% urban pruning and 90% sugarcane bagasse; T5 - 100% sugarcane bagasse

Figure 1. Results of diametric expansion of briquettes (A); Results of height expansion of briquettes (B)

Amaral et al. (2015) obtained mean maximum load between 50 kgf (490.3 N) and 52 kgf (509.9 N) for briquettes produced from two species of bamboo, that is, higher than the values of treatments T4 and T5 and lower than the values of treatments T1 to T3 of this study.

The low resistance of T4 and T5 briquettes in comparison to the others may have occurred because the particle size is not ideal for the compaction process, about 82% of the biomass residue was inside the thick particle class. According to the study of Kaliyan & Morey (2009), particles of different materials with smaller sizes resulted in pellet durability, resulting from a better accommodation and adherence of particles of the compacted material.

Based on the obtained results, T1 and T2 were the best treatments regarding the friability, since they proved to be slightly and averagely friable, respectively.

The lower the friability rate, the more resistant the briquette. It is likely that such behavior is related to the good conformation of the particles of the material, being juxtaposed to each other in a more organized manner, during the formation of the briquette (Dias Júnior et al., 2014).

Table 5. Tensile strength and briquettes friability

Treatment	Mean maximum tension (MPa)	Standard deviation	Mean maximum load (kgf)	Standard deviation	Friability rate (%)	Moisture content (%d.b.)
T1	1.54 a	0.17	167.14 a	17.38	3.49	13.7
T2	0.92 b	0.05	107.56 b	5.50	21.37	12.7
T3	0.60 c	0.06	72.80 c	6.09	46.17	11.9
T4	0.35 d	0.03	43.84 d	3.99	67.13	11.2
T5	0.24 e	0.40	31.19 e	4.45	69.78	10.8

*T1 - 100% of urban pruning; T2 - 50% urban pruning and 50% sugarcane bagasse; T3 - 25% urban pruning and 75% sugarcane bagasse; T4 - 10% urban pruning and 90% sugarcane bagasse; T5 - 100% sugarcane bagasse; Equal lowercase letters in the columns imply treatments with equivalent means, that is, that do not differ between them, at a 0.05 significance level

Conclusion

The addition of urban pruning residue provided improved mechanical performance to briquettes, attesting T1 and T2 as the most satisfactory treatments.

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