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CHARACTERIZATION OF RESIDUAL POWDERS FROM URBAN ARBORATION FOR FEASIBILITY ANALYSIS FOR SOLID FUEL PRODUCTION

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Abstract. The growth of society and economic activities generate an increase in the energy demand that sustains the productive processes, mainly in the industrial and transport sectors. Therefore, it becomes necessary to search for activities that cause less environmental impact. This work was structured based on the chemical and energetic characterization of residual biomass from the Neem (*Azadirachta indica*), Acacia (*Acacia cyanophylla*), and Ficus (*Ficus benjamina*) species originating from the urban afforestation of the municipality of Lavras da Mangabeira, Ceará, Brazil. The tree residues were submitted to a pre-treatment that consisted of drying at 100 °C for 24 h, crushing and sieving. Moisture, ash content, volatile material, fixed carbon and higher calorific value were analyzed, following the ASTM D5865-13 standard. The presented calorific value was 19.198^{22} MJ.Kg^{-1} for Neem, $19.505^{14.14}$ MJ.Kg^{-1} for Acacia and $17.339^{22.6}$ MJ.Kg^{-1} for Ficus. The values obtained in this study are very relevant for the production of briquettes, as they are considered high in terms of calorific value. Usually, the quality of a fuel is associated with its calorific value, because the higher it is, the greater the amount of energy contained in the matter. Therefore, it is possible to conclude that tree pruning residues can be used as solid biofuel in more sustainable energy processes.

***Keywords:** Tree residue, Powder, Calorific value, Solid fuel, Briquette.*

1. INTRODUCTION

Ongoing societal growth and the expansion of economic activities lead to a substantial rise in energy demand, particularly in the industrial and transportation sectors. This increasing demand is crucial for sustaining productive processes; nevertheless, it is imperative to take measures to mitigate the environmental impacts stemming from these activities. In this context, it becomes indispensable to search for and implement alternatives that foster a more efficient and sustainable utilization of energy resources, thereby reducing carbon footprint and minimizing harm to the environment. The transition towards activities with lower environmental impact represents an urgent challenge and a shared responsibility across all sectors of society.

According to Narzarya *et al*. (2023) renewable resources tend to be successors to traditional fossil fuels. Therefore, biomass is a crucial renewable resource. Biomass raw materials can produce by-products such as condensed solid fuel, ethanol, biogas, biodiesel, among others.

These actions carried out in order to meet the increased demand for food and energy are situations that arouse concern with the generation and consequent disposal of waste. Lignocelulósic residues, generated in large volumes, can cause significant environmental impacts when they are not adequately treated. Their high concentration of organic matter makes them an attractive source of nutrients for various microorganisms. This interaction can lead to the degradation of matter and the release of substances in inappropriate environments.

According to Miola *et al*. (2020), in the current consumption pattern of the population, products tend to be discarded before the end of their life cycle, being sent to landfills and dumps. Since the lack of reuse of these waste materials affects the lifespan of landfills, studies on the reutilization of municipal solid waste (MSW) are becoming more frequent, aiming for intelligent solutions for a sustainable future.

Therefore, one way to utilize this waste is by directing it towards briquette production, a process in which lignocellulosic residues are compacted. Production is carried out through briquetting, which is an efficient process that concentrates a large amount of energy from biomass in a small unit area. Briquettes have at least five times more energy than the waste materials from which they originated, and their calorific value is even higher than that of firewood. The reduction in volume achieved through briquetting is a factor that must be taken into account, given that large areas destined for the storage of waste can be reduced to much smaller dimensions, obtaining space gain, reduction of transport expenses, and greater gain of energy (Flores *et al*., 2009).

According to Souza *et al*. (2020), there are several routes for optimizing the utilization of these waste materials for energy. However, due mainly to their heterogeneity and low density, briquetting is currently one of the most technically and economically feasible alternatives to convert them into fuels with high energy density, and it is competitive compared to other sources.

According to Monte, Cardoso and Monte (2023), briquetting is a process of transforming the physical-chemical properties of materials of plant origin, which consists of several steps, with the aim of improving logistical and energy aspects. Thus, based on the literature, it is said that any vegetable organic matter has the potential to be transformed into briquettes.

According to Campos, Faria and Joele (2023), briquettes can be produced from biomass derived from non-fossil organic matter, presenting themselves as an alternative for renewable energy production. They can be used for heat generation, industrial thermal applications, electricity generation, and/or can be further converted into solid forms of energy.

Regarding the quality of the briquette, it is possible to highlight what was reported by Monte, Cardoso and Monte (2023) about the importance of considering particle size, as it is crucial for the quality and durability requirements of the briquette. This is because particle size is directly linked to the porosity of the product, a characteristic that can affect the burning process, which is inversely proportional to density. On the other hand, highly dense products have a lower combustion rate and burn for a longer period of time. Other factors are of fundamental importance and deserve attention, such as the storage of briquettes, as their organic nature makes them susceptible to decomposition.

In this sense, this work was structured based on the chemical and energy characterization of residual biomass from the species Neem (*Azadirachta indica*), Acacia (*Acacia cyanophylla*), and Ficus (*Ficus benjamina*) originating from the urban afforestation of the municipality of Lavras da Mangabeira/CE. The objective was to assess the technical feasibility and potential of using biomass energy from the generated powder waste of these types of residues for briquette production.

2. METHODOLOGY

Rejects from afforestation of the species Neem (*Azadirachta indica*), Acacia (*Acacia cyanophylla*) and Ficus (*Ficus benjamina*) from Lavras da Mangabeira/CE were used as biomass. The tree residues of the species in question were collected and submitted to a pre-treatment process.

The preparation of the raw material and pre-treatment was done by cutting it into pieces smaller than 5 cm, weighing them, and placing them in a Marconi brand oven, model MA 035, where the residue remained for 24 hours at 100 °C. It was then subjected to grinding in a macro knife mill, Mhtoli brand, model 050M020. These procedures were carried out in the Science Laboratory of the Full-Time High School, called Alda Férrer Augusto Dutra, located in the municipality of Lavras da Mangabeira/CE.

Subsequently, the residue was taken for mechanical sieving using a Matest brand sieve, with the purpose of standardizing the granulometry of the biomass. An 80 mesh size sieve with a vibration of 60 (shaking) was chosen.

For moisture determination, 1 g of dry basis residue of each species was used. The moisture content was based on the determination of the weight loss of the product submitted to heating at 105 °C, until reaching a constant weight. The test was performed using an analytical balance for moisture determination, AND brand, model MF-50.

The ash content or fixed mineral residue corresponded to the residue obtained by incineration at temperatures of 550°C until light ash was obtained. The analysis was performed in triplicate using 2 g of the residue of each species.

The volatile material analysis corresponded to the residue obtained by incineration at temperatures of 950 °C. The analysis was performed in triplicate using 1 g of the residue. To carry out these analyses, crucibles, a Quimis muffle furnace, and a precision scale, Aaker brand, model M214Ai, were used.

The determination of the fixed carbon content was based on the residual fraction, being the remaining material from the release of the volatilized fraction of the sample. For this purpose, Eq. (1) was used.

$$FC = 100 - (VM + AS) \tag{1}$$

where, FC(%) is the percentage by mass of fixed carbon, VM(%) is the percentage by mass of volatile material and AS(%) is the percentage by mass of ash.

For the energetic characterization of the produced residual powders, the higher calorific value (HCV) was investigated, which was determined by the ASTM D5865-13 standard. There are two measures commonly taken to investigate biodegradation. The first, known as the ‘primary step’ (radation), measures the reduction of carbon and hydrogen bonds (C – H) in the initial solution, and the second measure of biodegradation is the ‘secondary degradation’ or ‘final degradation’, which measures the evolution of CO_2 emissions through biodegradation (Miller, 2012). The analysis was performed using an IKA bomb calorimeter, model C-200.

The process of mechanical sieving, moisture, ash, and volatile content, as well as fixed carbon content and calorific value, were conducted at the Laboratory of Materials and Environmental Chemistry (LabMaQ) of the Department of Renewable Energy Engineering (DEER), at the Center for Alternative and Renewable Energies (CEAR) of the Federal University of Paraíba (UFPB).

In order to identify changes in thermal and structural properties, the samples were analyzed by differential scanning calorimetry (DSC) and thermogravimetry (TG). The TG/DSC curves were obtained on an SDT 650/Discovery thermobalance. Samples weighing approximately 6 mg were placed in a platinum sample holder under an inert atmosphere of N_2 and heated from 0 to 900 ºC at 10 ºC min^{-1}. The analysis was carried out at the Laboratory of Synthesis and Characterization of Thin Films (LabFilm) at DEER/CEAR/UFPB.

3. RESULTS

Concerning the dry basis (DB) moisture content of the residual biomass from the three different tree species, Table 1 shows that these values were very close, probably because they are species from the same regional location. For Nim, it was 8.80%; for Acacia, 9.15%; and for Ficus, 9.20%. The moisture content indicates the amount of water present in organic matter and can be expressed in both wet and dry bases. The moisture measurements obtained can be compared with those found by Narzarya *et al*. (2023) for rice straw, which showed 8.11% moisture content. In the study carried out by Yiga *et al*. (2023) the moisture content observed for cassava peel flour was 9.1% and for cassava peel it was 10.9%. Cavalcanti *et al*. (2020) presented DB moisture values of 10.45% for the residual biomass of mesquite. It is essential to highlight that high moisture levels can interfere with the higher calorific value, consequently making the raw material less efficient for briquette production.

Table 1. Experimental results of the immediate and energetic characterization of residual biomass from the three tree prunings under study.

Properties	**Neem**	**Acacia**	**Ficus**
Dry basis moisture (%)	8.8	9.15	9.2
Ashes (%)	12.20	9.86	17.26
Volatile material (%)	$65.24^{0.1}$	$65.43^{0.3}$	$64.12^{0.2}$
Fixed carbon (%)	$22.58^{0.2}$	$23.90^{0.1}$	$18.55^{0.1}$
HCV (MJ.Kg^{-1})	19.198^{22}	$19.505^{14.14}$	$17.339^{22.6}$

In the determination of ash content, which relates to the inorganic fraction present in the material, it was found that the percentage obtained for the residual biomass from Ficus was higher than that of samples from Nim and Acacia. The results of the tests conducted with the residual biomass of Neem were 12.20%, of Acacia were 9.86%, and of Ficus were 17.30%, as shown in Table 1. In the works by Tavares and Santos (2013), ash content was observed for different biomasses, with elephant grass showing 9.40%, carnauba straw with 9.74%, and macrophytes with 29.67%. On the other hand, in a study conducted by Moura *et al*. (2021), ash content values of 3.30% were obtained for the residual biomass of corn straw. In the study conducted by Duangkham and Thuadaij (2023), the ash content percentage was found to be 16.5% in the sample of rice straw and banana peel charcoal.

Therefore, it is possible to observe close values when comparing lignocellulosic biomasses, ranging from 8% to 18%. Other higher or lower values are reported in the literature, and it is important to highlight that these differences may be caused by factors related to the treatment of the raw material, the use of two or more biomasses as components of the analyzed mixtures, and other variables that can influence the results. These percentage values obtained from ash determinations represent the residual composition of the material, which is what remains after the consumption of organic matter. At the end of the process, ashes are what are left and commonly released into the environment as particulate matter, becoming a liability for thermochemical processes. Furthermore, high ash content promotes the formation of deposits, leading to scaling and corrosive processes in equipment used in thermochemical routes (Xing *et al*., 2016).

In the analysis of volatile material, it was noticed that the values for the three species were remarkably close, with all of them exceeding 60%. The results were $65.24^{0.1}$% for Neem residual biomass, $65.43^{0.3}$% for Acacia residual biomass, and $64.12^{0.2}$% for Ficus residual biomass. In the study conducted by Marchese *et al*. (2018), volatile material content of 73.80% was found for wheat bran, 76.20% for wood sawdust, and 77.50% for sugarcane. The studies carried out by

Moura *et al*. (2021) found a volatile material value of 69.56% for the residual biomass of corn straw. Additionally, a value close to that found in the present study is also reported in the results presented by Yiga *et al*. (2023), who analyzed cassava peel flour and found a volatile material content of 72.9%.

The tests related to fixed carbon also showed similar values, with the Acacia residual biomass being the one with the highest percentage, which was $23.90^{0.1}$%. The residual biomass of Neem was $22.58^{0.2}$% and Ficus was $18.55^{0.1}$%. The values related to fixed carbon demonstrate the material's behavior during combustion, indicating whether the process is slow or fast. It is important to mention that, especially for thermochemical processes, particularly when dealing with solid fuel, it is crucial for the combustion to occur slowly, thereby expressing higher energy efficiency. Other diverse biomasses are studied concerning their fixed carbon content. For instance, in the study conducted by Marchese *et al*. (2018), fixed carbon values of 13.10% for sugarcane, 15% for wheat bran, and 13.90% for wood sawdust were found. In the research by Tavares and Santos (2013), a value of 34.41% was observed for rice straw.

The residual biomass from the three studied biomasses exhibited significant values of higher calorific value (HCV). The lowest HCV was found in the Ficus residue, at 17.33 $MJ.Kg^{-1}$. For the Neem residue, the HCV was 19.20 $MJ.Kg^{-1}$, and for Acacia, it was 19.51 $MJ.Kg^{-1}$. These obtained values can be compared to those reported by Cavalcanti *et al*. (2020), who found an HCV of 18.94 $MJ.Kg^{-1}$ in a study conducted with the biomass of mesquite.

The data obtained in this study are considered ideal for the production of briquettes (solid fuel) due to their high heating values. This assertion is supported by the comparison with firewood, which, according to Caires (2010), has a heating value ranging from 7.112 to 10.460 $MJ.Kg^{-1}$.

The higher calorific value (HCV) refers to the energy released as heat during the thermochemical process applied to the raw material, in this case, lignocellulosic biomass. These values are heavily influenced by the organic matter composition as well as technical conditions associated with combustion, such as pre-treatment of the material. Based on the results obtained in this study, it can be confidently stated that the residual biomass from tree pruning of Neem, Acacia, and Ficus species are excellent and sustainable alternatives for briquette production.

The thermal profile of the residual samples was determined using thermogravimetry, which consists of the destructive technique in the field of thermal analysis, in which the variation of sample mass as a function of temperature is monitored, allowing the analysis of mass loss. In the Acacia TG-DSC curves (Figure 1), a significant event was observed, with an initial temperature of 158 °C and a final temperature of 518 °C with a mass loss of 64.5%. Regarding the residual sample of Ficus (Figure 2), a significant event was also observed, with an initial temperature of 201 °C and a final temperature reaching the temperature range of 534 °C, with a mass loss of 58%. In relation to the curve observed for the Neem residue (Figure 3), there was an event with an initial temperature of 147 °C, ending at 534 °C, and a mass loss of 61%.

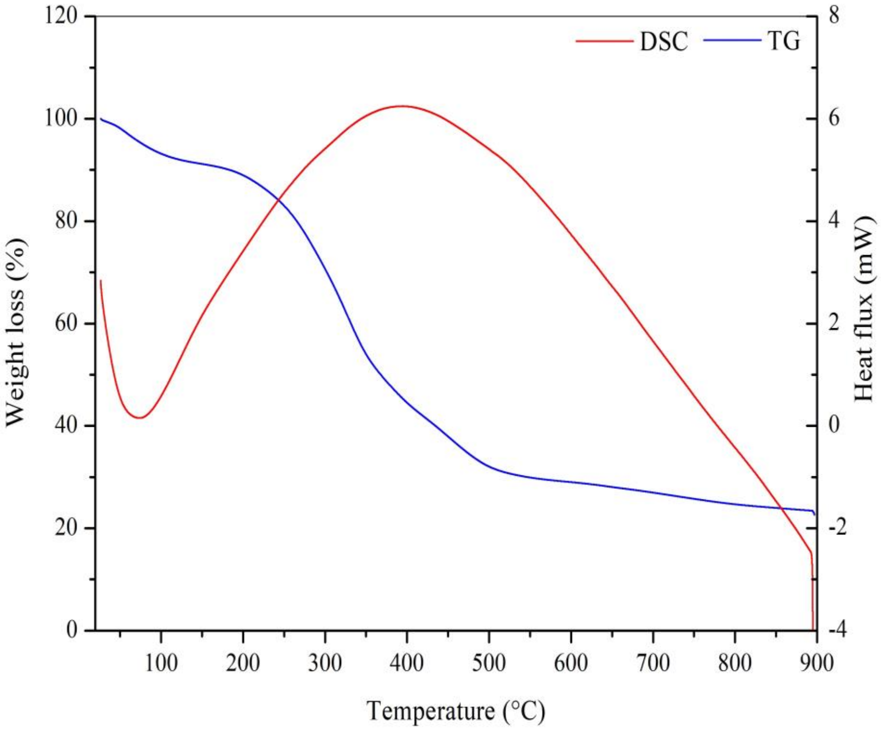

Figure 1. TG and DSC curves of the residual sample from the pruning of the Neem tree species, obtained with a heating rate of $10°C.min^{-1}$, under an inert atmosphere of N_2 and air (100 $mL.min^{-1}$).

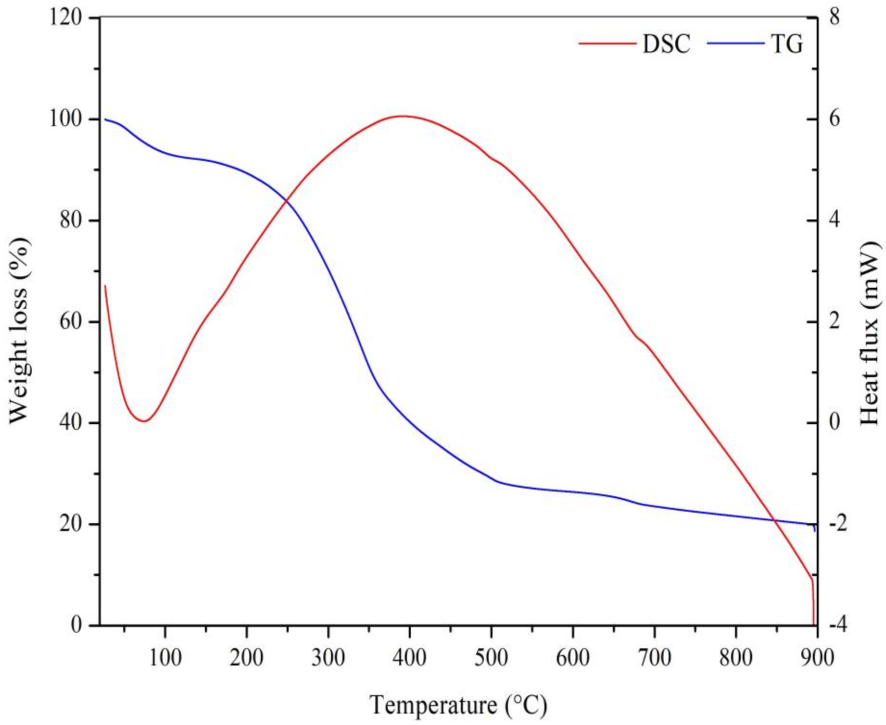

Figure 2. TG and DSC curves of the residual sample from the pruning of the Acacia tree species, obtained with a heating rate of 10°C.min^{-1}, under an inert atmosphere of N_2 and air (100 mL.min^{-1}).

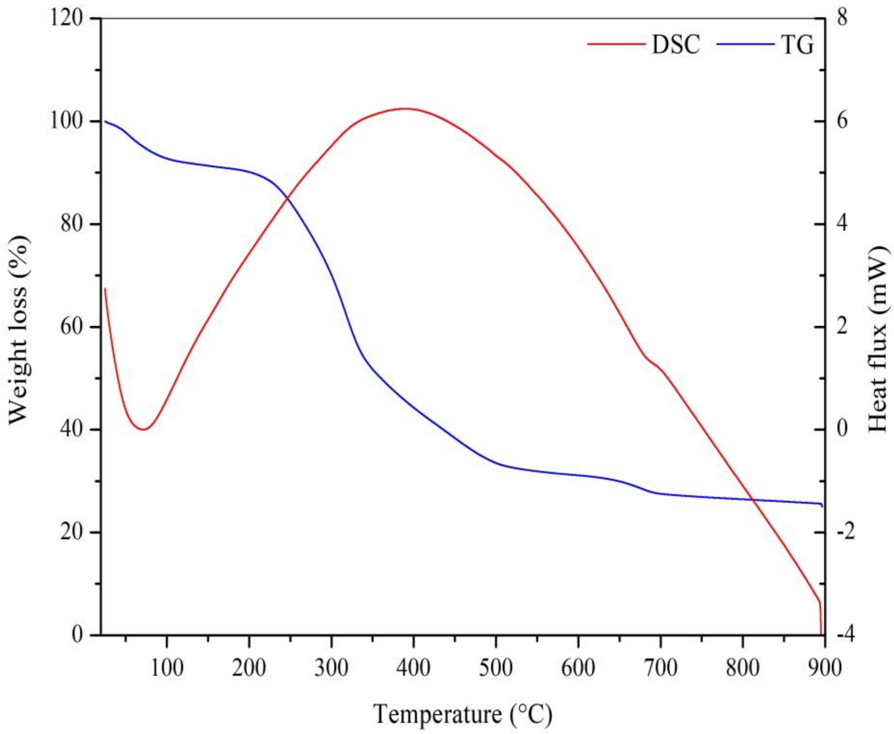

Figure 3. TG and DSC curves of the residual sample from the pruning of the Ficus tree species, obtained with a heating rate of 10°C.min^{-1}, under an inert atmosphere of N_2 and air (100 mL.min^{-1}).

The significant events mentioned can be attributed to the degradation processes of the main components of the studied biomasses (cellulose, hemicellulose and lignin). Thermal degradation of hemicellulose, cellulose and partially of lignin occurs when subjected to temperatures above 220 ºC (Furtado *et al*., 2010). According to Fernandes *et al*. (2011) in their research with banana crop residues, the degradation of volatiles (hemicellulose, cellulose and lignin) occurred from 150 to 420 ºC. Above 420 ºC was considered the lignin degradation zone.

Presenting results on lignocellulosic material in an analysis carried out with a wood sample, Florentino-Madiedo *et al*. (2021) showed that most of the hemicellulose and cellulose decomposes in the first stage around 290 and 348 °C. However, lignin is decomposed with a maximum decomposition in a temperature range between 400 and 450 °C (depending on the heating rate), and lignin decomposition continues up to 900 °C, corroborating other data observed in the literature.

In relation specifically to the DSC curves presented in Figures 1, 2 and 3, it is possible to observe that as the temperature increased to approximately 250 °C, the point of intersection between the TG and DSC curves, an endothermic energy absorption event occurred, possibly related to the degradation of matter. Then, with increasing heating, an exothermic event occurred with heat release that is related to the combustion and decomposition process of lignocellulosic matter that extended to the intersection of the TG and DSC curves at approximately 810 °C.

4. CONCLUSIONS

The preliminary study of residues generated from tree pruning in the city of Lavras da Mangabeira/CE, revealed that this waste generates a substantial amount of raw material that can be used as a biomass source. Given that pruning is a recurring activity carried out by the population, these residues hold significant potential for biomass utilization.

The results regarding the immediate composition of the residual biomass from pruning provide crucial information to assess the viability of its energy processing. Regarding the studied proximate composition levels, there was agreement with values reported in the literature. Regarding the ash content levels found, it can be stated that they align with the literature, emphasizing that lower ash content results in fewer issues related to equipment fouling and corrosion. Concerning the volatile material, it is evident that the levels fall within the range found in the literature. It is important to add that these levels do not compromise the biomass's heating value but rather demonstrate a high reactivity during the combustion process. Regarding the fixed carbon values, they align with what is proposed in the literature for direct combustion purposes, emphasizing the significance of this parameter in achieving slower fuel consumption, making the energy production process more enduring and efficient.

The preliminary study of the calorific value using arborization residues demonstrated their potential as raw material for briquette production. Notably, the highest higher calorific values (HCV) were obtained from the biomass of the Neem and Acacia species. When comparing the HCV values from this study with those reported in the literature, it became evident that the biomass derived from tree pruning residues in the Municipality of Lavras de Mangabeira could be harnessed as a solid biofuel in more sustainable energy processes. Remarkably, the HCV values found were even higher than the value reported for firewood.

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