

COB2023-1019 STUDY OF METHODOLOGIES FOR DETERMINING HIGHER AND LOWER HEATING VALUE THROUGH PROXIMATE ANALYSIS OF EUTERPE OLERACEA

Gabriel Willian Moreira Bezerra¹

Luiz Felipe da Silva Ferreira²

Ana Paula Mattos³

Fernando Henrique de Barbosa Santos⁴

Alan Nogueira Carneiro⁵

João Victor Ribeiro Moreira⁶

Universidade Federal do Pará, Rua Augusto Corrêa 01, Guamá, 66075-110, Belém, Pará.

gabrielbezerra11@gmail.com¹; luiz.silva.ferreira@itec.ufpa.br²; anapmattos@ufpa.br³; fernandohenrique13@yahoo.com.br⁴; alancarneiro90@gmail.com⁵; joao.moreira@itec.ufpa.br⁶.

Abstract. *In the study of the combustion of new biofuels or residues with energy potential it is of utmost importance to study the physical-chemical properties to predict the combustion phenomenon and estimate the energy produced. Some analyses are extremely necessary to study combustion, such as: proximate analysis, ultimate analysis, thermogravimetric analysis, and obtaining the higher heating value (HHV) and lower heating value (LHV). The Euterpe Oleracea stone is an abundant residue in the state of Pará, about 80% of the mass of the fruit is the stone. About 16 tons are produced daily in the metropolitan region of Belém. The LHV of the açai stone is comparable to the mineral coal of Santa Catarina, and is higher than that of sugar cane bagasse with 20% humidity. Recent studies are focused on energy generation from waste, Brazil is a pioneer in the use of renewable energy, with about 84.8% of the domestic supply of electricity comes from clean sources, among this figure biomass represents 9.1% of this matrix, being the second largest source, only behind hydropower. Research to develop technologies for the use of waste is growing, aiming a greater generation of decentralized energy and a greater use of biomass in the boilers of large industries, which can generate carbon credits, reduction in the use of coal, decrease in emissions of pollutants and greenhouse gases (GHG). This work aims to explore existing literature for equations that can determine lower heating values using data acquired from proximate and elementary analyses, eliminating the necessity for costly equipment. The primary objective is to facilitate a more extensive and efficient study of the energy potential of açai seeds, thereby promoting their enhanced utilization as a biofuel source and subsequently mitigating carbon emissions resulting from conventional fuel combustion.*

Keywords: *Euterpe Oleracea, Proximate analysis, HHV, LHV, Biomass.*

1. INTRODUCTION

The environmental issue has always gained prominence in the global scenario due to the consequences of the uncontrolled use of natural resources and the lack of effective actions to combat such problems. For over 15 years, concepts such as bioeconomy, sustainability, circular economy, and resource efficiency, among others (Patermann, 2021) have evolved, allowing several initiatives to emerge around the globe to ensure a greener future. Given this context, there is urgency to develop more efficient means of obtaining energy and reusing waste. The diversification of the energy matrix and studies conducted to broaden knowledge are viable devices to achieve production with less generation of gases and waste that are harmful to the environment. Brazil has shown a growth in the share of renewable sources in the domestic energy supply, with an increase from 46.1% in 2019 to 48.4% in 2020, with sugarcane standing out with 19.1%, followed by hydraulic sources with 12.6%, firewood, and coal with 8.9%, and other renewable sources with 7.7% (MME, 2021). Among the biomass sources, when considering the participation in electricity generation, the highlight is the sugar cane bagasse residue, with an installed capacity of 11,712 MW, other residues, such as rice husk, wood residue, charcoal, etc., have a smaller participation, with 3,594 MW (MME, 2021).

In the Brazilian energy context, the waste from Euterpe Oleracea production has a small share in energy generation, however, given its great potential within the production chain of the Amazon region, such waste is an attractive alternative as a source of renewable energy. The state of Pará, in the year 2019, presented a production of the fruit in the order of 1.4 million ton of which, about 30% is composed of pulp and 70% is composed of the fibrous stone (SENAI CETIQT, 2021). The increase in the production of the fruit is accompanied by the generation of fibrous stone waste,

therefore, policies and studies for the correct management of this waste are necessary, with the creation of a database of logistics and physicochemical properties, methodologies for the use of this biomass as an efficient energy source.

One of the most important properties is the heating value, which represents the maximum amount of energy available in the fuel released during the complete combustion process and is divided into the higher heating value (HHV) and the lower heating value (LHV) (Turns, 2013 and Çengel, 2013). Both are indispensable properties in the dimensioning of thermal systems, such as boilers and gasifiers. Given their importance, their determination by experimental means requires adequate equipment, such as the calorimetric pump. Nonetheless, in situations where resources are limited, the most practical approach is to employ empirical equations to determine the heating value. Numerous authors (Nhuchhen, 2012; Yin, 2011; Demirbas, 1996; Jimenez, 1991, and others) have extensively researched these equations, drawing from diverse databases and incorporating models based on various properties, including proximate and ultimate analysis data, as well as equations tailored to specific biomass types. The primary objective of this study is to evaluate the array of empirical equations available in the literature for estimating the higher heating values and lower heating values of açaí kernels, utilizing laboratory-obtained data from proximate analysis of this material.

2. JUSTIFICATION

Agroforestry residues are an abundant and low-cost renewable stock, and thus should be considered as a renewable source, contributing to the reduction of pollutants generated by combustion, which come from the process of millions of years of organic decomposition and aggravators of the greenhouse effect (SOUZA et al., 2021). According to the Brazilian Institute of Geography and Statistics (IBGE), in the Municipal Agricultural Production (PAM) of 2021, the State of Pará is the first in the production of açaí, with about 94.03% (1,389,941 tons). Thus, it can be seen the large amount produced, and much of it is not reused, because the rate of reuse of the açaí stone is very low, causing much of the waste to be improperly disposed in rivers, streams, roads, and vacant lots (RODRIGUES, 2018). Figure 1 presents some data of planting and fruit yield, it is noted that around 15 to 25% is transformed into pulp for consumption and this small amount generated is offset by increased productivity, i.e., tons of açaí stone without destination acquired after extraction of the fruit pulp.

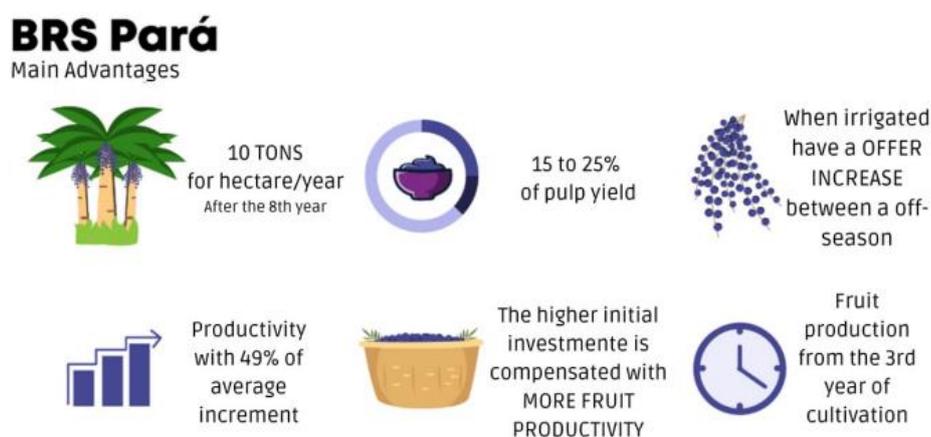


Figure 1. Euterpe Oleracea production and income data in Pará.
Source: Embrapa, 2005 (adapted).

Allocating an energy purpose for the use of this waste, solves, in part, the problem of improper disposal of açaí stone in the regions of the state. The use of biomass as a source of energy requires knowledge of its higher heating value (HHV) and lower heating value (LHV). For this, the calorimetric pump and elemental analyzer can be used, but this equipment and the instruments necessary for its operation have a high cost. A more economical way would be to use empirical formulas that calculate the heating value through the values of moisture content, volatile materials, fixed carbon and ash obtained in the approximate analysis of biomass.

3. METHODOLOGY

This work is characterized as a literature review of different empirical equations of higher and lower heating values (HHV and LHV, respectively), found in different literatures, in order to validate them qualitatively, using the experimental database of the proximate analysis of different samples of açaí stone biomass, which were obtained in the laboratory of biomass characterization - LacBio (UFPA). Figure 2 shows photos of the açaí samples A, B and C used.



Figure 2. Euterpe Oleracea seed samples A, B e C.

The proximate analysis aims to quantify the moisture content, volatiles (condensable and non-condensable) and fixed carbon contained in a biomass sample. Depending on the procedure adopted to make the quantifications, different results may be obtained in the end (Rendeiro and Nogueira, 2008). Some samples of açai stone were subjected to proximate analysis, i.e., an oven was used to dry the samples to determine the moisture content (%), the muffle was also used to burn the samples studied in order to determine the ash content (%) and volatile content (%), and a calorimetric pump in order to quantify the high heating value of the açai stone and finally the weighing of everything before and after each procedure by a precision analytical balance. All the procedures mentioned above followed methods defined by international standards for proximate analysis of various biomasses (CEN.TS 14774-1, 2004) (CEN.TS 14775, 2004) (CEN.TS 15148, 2005). Figure 2 shows the muffle furnace where the burning of the samples for the determination of volatiles and ash was performed.



Figure 3. Muffle furnace JUNG.

The validation of these formulations for the residue of açai stone included the standardization of empirical equations in Microsoft Excel[®] spreadsheets for the purpose of insert proximate analysis values. A comparison between experimental and estimated values was performed in order to select equations with lower standard deviations and relate these data through graphs and discussions that encompass the properties of the higher and lower calorific values estimated by calculation, in combustion. Furthermore, the replacement of fossil fuel energy sources is a gradual and somewhat undemocratic process. With the methodology used in this work, it is possible to extend the obtaining of thermodynamic properties (HHV and LHV) of biofuels through the use of empirical formulations with admissible errors when compared to data obtained in biomass characterization laboratories. Table 1, presents 6 equations for calculating the higher heating value (HHV) from proximate analysis, that gives fixed carbon (FC), volatile matter (VM) and ash

content (ASH), which were listed with the name of the authors and the equation was developed, but the equations were manipulated for their results to be given in MJ/kg.

Table 1 – Equations for calculating HHV from immediate analysis

Authors	Equations
Ferreira et. al, 2014.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{4.184 * (85.5104 * \text{FC} + 37.2601 * \text{VM} - 1.8642 * \text{Ash})}{1000}$
Yin, 2011.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = 0.1905 * \text{VM} + 0.2521 * \text{FC}$
Nhuchhen, 2012.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = 19.288 - \left[0.2135 * \left(\frac{\text{MV}}{\text{FC}} \right) - 1.9584 * \left(\frac{\text{Ash}}{\text{FC}} \right) + 0.0234 * \left(\frac{\text{FC}}{\text{Ash}} \right) \right]$
Parikh et. al, 2005.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = 0.3536 * \text{FC} + 0.1559 * \text{VM} - 0.00078 * \text{Ash}$
Cordero et. al, 2001.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = 0.3543 * \text{FC} + 0.1708 * \text{VM}$
Sheng e Azevedo, 2005.	$\text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = 19.914 - 0.2324 * \text{Ash}$

Table 2 shows the equations of several authors for estimated LHV; however, the equations were manipulated so that their results are given in MJ/kg. In this part of the work we used values of volatile content (VM), moisture content (W), ash content (ASH), fixed carbon content (FC), experimental higher heating value (HHV) and experimental Lower Heating Value (LHV) of two authors as a reference for the comparison of experimental and calculated LHV. As shown in table 3, the authors Oliveira, 2021 and Rendeiro, Nogueira, 2008 were used.

In addition, the data was organized for analysis with the help of Microsoft Excel ® and the equations for creating graphs, calculating the average lower heating value and standard deviations of the comparison between the lower heating value estimated by the formulations and the experimental lower heating value presented in the reference literature.

Table 2. Equations for calculating LHV from immediate analysis, HHV and hydrogen content (H) (from immediate analysis).

Authors	Equations
Parikh, 2007.	$\text{H} = 0.052 * \text{FC} + 0.062 * \text{VM}$
Cittadino apud Oliveira, 2016	$\text{LHV}_w \left(\frac{\text{MJ}}{\text{kg}} \right) = \text{HHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) - 600 * \text{W}$
Poli et.al, 2013	$\text{LHV}_w \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{(1-\text{W}) * \text{HHV}_d \left(\frac{\text{kJ}}{\text{kg}} \right) - (\text{W} * \text{H}_{\text{lv}}^{(1)})}{1000}$
JNMSWF, 1991 (1)	$\text{LHV}_w \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{[(45 * \text{VM} - 6 * \text{W}) * 4.1868]}{1000}$
JNMSWF, 1991 (2)	$\text{LHV}_w \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{[(44.75 * \text{VM} - 5.85 * \text{W} + 21.2) * 4.1868]}{1000}$
Cunha e Goes, 2022	$\text{LHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{\left[\text{HHV}_d \left(\frac{\text{kJ}}{\text{kg}} \right) - (\text{H}_{\text{lv}}^{(2)} * 9 * \frac{\text{H}}{100}) \right]}{1000}$
Candéo et. al, 2012	$\text{LHV}_d \left(\frac{\text{MJ}}{\text{kg}} \right) = \frac{\left\{ \left[\text{HHV}_d \left(\frac{\text{kcal}}{\text{kg}} \right) - (600 * 9 * \frac{\text{H}}{100}) \right] * 4.1868 \right\}}{1000}$

⁽¹⁾25°C =2441 kJ/kg; ⁽²⁾20°C =2452.5 kJ/kg.

4. RESULTS AND DISCUSSIONS

There were 4 samples of açaí processed in the laboratory of biomass characterization of UFPA, identified as açaí stone Rendeiro and Nogueira, 2008 (data from literature) and açaí stone A, B and C, which were used for the proximate analysis that has the function to establish values of moisture content (W), volatile content (VM), ash content (ASH),

fixed carbon content (FC) and obtaining higher heating value (HHV) through a calorimetric pump Ika Werke C2000, as shown in table 4.

Table 3. Immediate analysis data and HHV of the açai seeds under in study.

Açaí samples	VM (%)	W (%)	Ash (%)	FC (%)	Experimental HHV (MJ/kg)
Açaí sample of Rendeiro e Nogueira, 2008	65.00	14.00	1.00	24.00	19.00
Açaí sample A	79.53	20.44	1.06	19.41	18.16
Açaí sample B	78.05	34.65	1.21	20.75	18,69
Açaí sample C	77.70	45.83	1.97	20.33	18.66

Based on the collected information, Microsoft Excel ® was used to organize the proximate analysis and Higher heating value data, and thus the application of the empirical formulas researched. After that, we established comparative graphs of the higher calorific value between the various authors used with the data obtained in the laboratory of biomass characterization of UFPA, in addition to calculating the mean and standard deviations for the higher heating values under analysis of the different samples of açai under study (stone açai of Rendeiro and Nogueira, A, B and C).

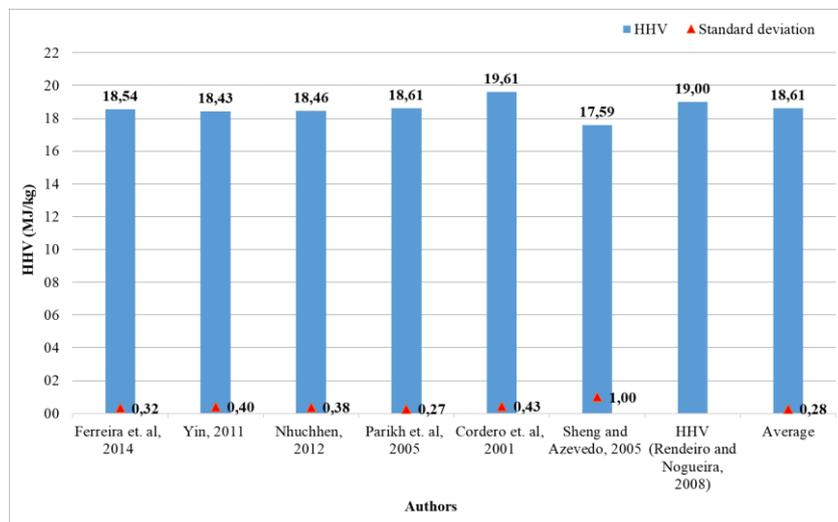


Figure 4. Comparison of experimental HHV and HHV calculated, açai samples of Rendeiro e Nogueira.

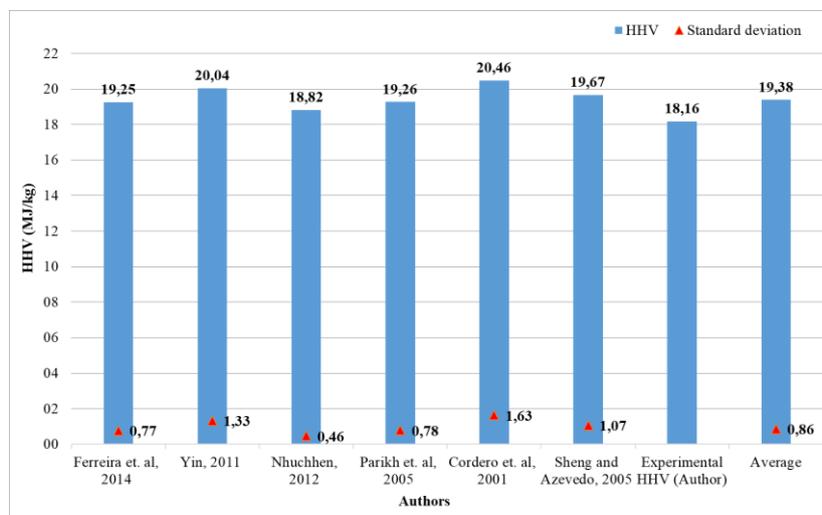


Figure 5. Comparison of experimental HHV and HHV calculated, açai sample A.

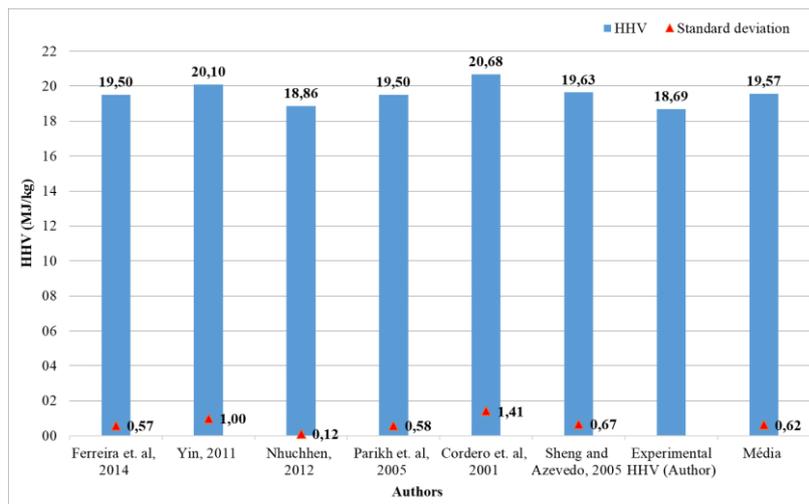


Figure 6. Comparison of experimental HHV and HHV calculated, açai sample B.

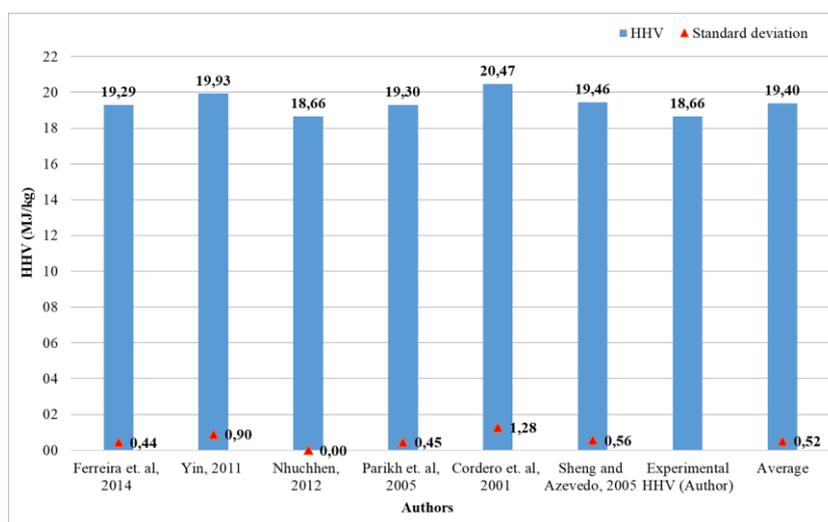


Figure 7. Comparison of experimental HHV and HHV calculated, açai sample C.

Figures 4, 5, 6 and 7 show the graphs generated in bars (in blue) and the standard deviations calculated between experimental HHV and estimated HHV in the dispersion format (points in red). All formulations used presented values close to the HHV obtained in the laboratory and in literature, i.e., very considerable deviations if related to the real value. Thus, making their use feasible for studies to determine the HHV, because the difference between experimental and empirical results is less than 1.63%. Moreover, the açai stone of Rendeiro and Nogueira, 2008 showed a lower standard deviation in the equation of Parikh, (2005), varied around 0.01% in relation to the deviation from the mean and higher deviation in the equation of Sheng and Azevedo, (2005), and varied about 0.72% in relation to the deviation from the mean. On the other hand, açai kernels A, B and C showed lower deviations in the equation proposed by Nhunchhen, 2012 (0.46%, 0.12% and 0.003%, respectively) and higher deviations in the equation proposed by Cordero et al., 2001 (1.63%, 1.41% and 1.28%, respectively). Due to the different ways of assembling the empirical correlations for determining calculated HHV, some deviations differ, because some equations are built from a database of different biomasses (for example Parikh 2005 and Nhunchhen 2012) and others are built from correlations between equations of other authors (for example Sheng and Azevedo 2005).

A similar approach was adopted in the investigation of the Lower Heating Value (LHV). The quest involved seeking equations that incorporated not only proximate analysis and high heating value but also the hydrogen content calculated from the proximate analysis. (Parikh, 2007).

Table 4. Immediate analysis data, HHV and LHV founded in literatures of Oliveira, 2021 and Rendeiro e Nogueira, 2008.

Açaí samples	VM (%)	W (%)	Ash (%)	FC (%)	Experimental LHV (MJ/kg)	Experimental LHV (MJ/kg)
Açaí sample of Oliveira (2021)	63.00	10.00	1.00	26.00	19.75	16.57
Açaí sample of Rendeiro e Nogueira (2008)	79.40	20.44	1.10	19.50	19.16	14.00

Once this was done, comparative graphs of these values were generated, being the lower heating values and average, the blue bars, and the standard deviations between the real and empirical values, the orange dots. It is possible to observe that although the deviations of figures 8 and 9 are higher, in relation to figures 4, 5, 6 and 7, they still have acceptable values for empirical calculation of LHV, demonstrating the great applicability of the formulas as a means of reducing costs of ultimate analysis to determine experimental LHV.

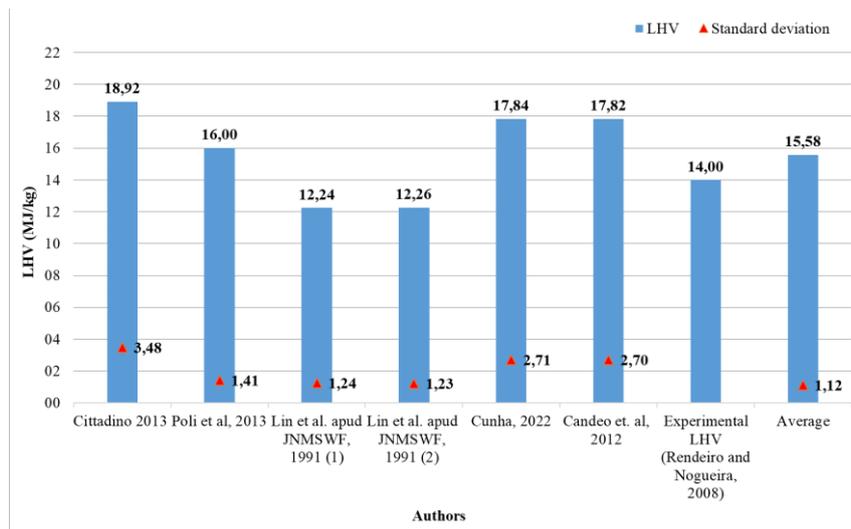


Figure 8. Comparison of experimental LHV and LHV calculated, caroço Rendeiro e Nogueira, 2008.

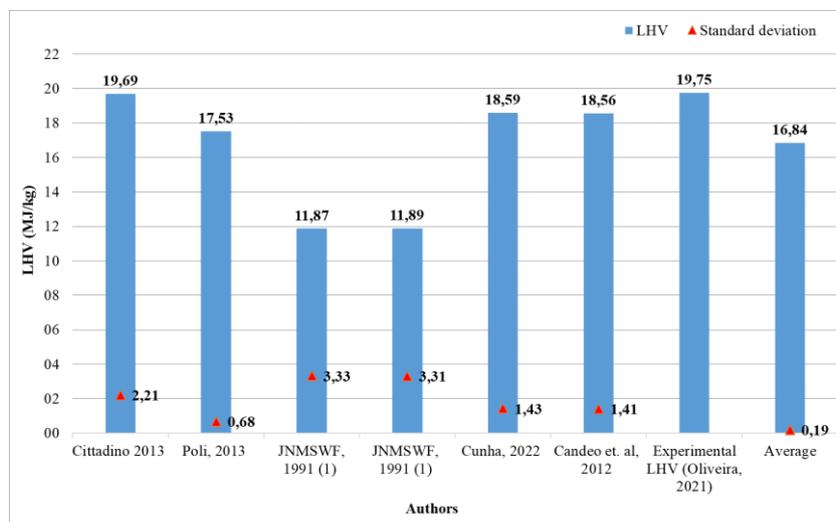


Figure 9. Comparison of experimental LHV and LHV calculated, caroço Oliveira, 2021.

Figure 8 shows that for the comparison between estimated and experimental LHV data of Rendeiro and Nogueira (2008), the average lower heating value (LHV) was 15.58 MJ/kg and the lowest deviation in the equation proposed by Lin et al. apud JNMSWF (2013), 1.23%, such proximity can be analyzed by the scope of solid waste that the equations proposed by Lin et al. apud JNMSWF (2013) work. In figure 9, for the data of Oliveira (2021), the average lower heating value (LHV) was 16.84 MJ/kg and the lowest deviation, 0.68%, was in the equation proposed by Poli et al. (2013), such proximity can be justified because the equation used by Poli et al. (2013) covers solid fuels with high moisture content, which can be included the açai samples used, without any kind of pre-treatment, by Oliveira (2021).

Thus, one can validate the estimation of the LHV calculation from these equations for analyses in açai stones, as already demonstrated in the comparative figures 4, 5, 6 and 7, these being a low-cost artifice in the replacement of an elemental analyzer that provides values of percentage elements generated in combustion, such as carbon, hydrogen, oxygen, nitrogen, and sulfur (C, H, O, N, S) for calculating the lower heating value.

5. CONCLUSION

Açai is a fruit consumed on a large scale throughout the country and has a large production in the northern region of Brazil, with about 1.39 million tons produced only in the state of Pará (dryland and floodplain açai) (IBGE, 2020) and if the fruit has about 80% stone, then the açai seed ends up being a waste generated in large numbers. Assigning an energy purpose, from combustion, for this waste promotes not only the proportion of green CO₂, but also the reuse in general of a waste widely discarded in the region of Pará.

The higher and lower heating values are extremely important for determining the amount of energy that will be offered during combustion, differentiated by the water resulting from this combustion, water resulting in vapor for LHV (not offering heat to the system) and water resulting in the liquid phase for HHV (offering and adding heat to the system). However, the means for obtaining these heating values are of considerable cost and require a certain type of knowledge for correct handling, since a calorimetric pump is needed to obtain a higher heating value and a calorific analyzer (expensive machinery) is generally used to obtain a lower heating value.

The best correlations for the calculation of HHV and LHV were determined from the analysis of the deviations that they presented in relation to experimental values used in this article, and it was also possible to realize that the smallest deviations between calculated and experimental values can be explained according to the similarity between the samples under study in the literature. For example, the literature with larger databases of different types of biomass present values of HHV closer to the experimental, as occurred with Parikh (2005) and Nhunchen (2012). Furthermore, for the calculated and experimental LHV values, it was noted the treatment format or even sample type influenced the smaller deviations, as occurred with Lin et.al apud JNMSWF (2013) and Poli et.al (2013).

Diverse methods of constructing empirical correlations to calculate the Higher Heating Value (HHV) result in variations in deviations. These differences stem from the fact that certain equations are derived from databases containing various types of biomass, while others are based on correlations between equations developed by different authors.

Efficiency in assessing the energy potential hinges on the widespread accessibility of lower heating value data for biomass. Thus, prioritizing equations over expensive equipment becomes crucial in making this valuable information readily available.

Finally, the comparison of the equations for estimation of HHV and LHV with experimental values allows the feasibility of the equations under study to obtain these fuel properties for the açai stone, the use of standard deviation, arithmetic mean, and graphical demonstrations, presents the applicability of these empirical formulations as a low cost alternative and democratization of the calculation of the heating values for further work on the characterization of the açai stone, as a biofuel alternative.

6. REFERENCES

- Candéo, R. A., Lopes, C. F. P., Bittencourt, J. V. M., et al. "Classificação energética dos resíduos de madeira de Pinus utilizados para a geração de energia calorífica em função do poder calorífico e teor de umidade", II Congresso Brasileiro de Engenharia de Produção, 2012.
- CEN/TS, 14774-1. Solid biofuels - Methods for determination of moisture content - Oven dry method - Part 1 : Total moisture - Reference method., 2004.
- CEN/TS, 14775. Solid biofuels - Method for the determination of ash content., 2004.
- CEN/TS, 15148. Solid biofuels - Method for the determination of the content of volatile matter., 2005.
- Cordero, T., Marquez, F., Rodriguez-Mirasol, J., et al. "Predicting heating values of lignocellulosics and carbonaceous materials from proximate analysis", *Fuel*, v. 80, n. 11, p. 1567–1571, 2001. DOI: 10.1016/S0016-2361(01)00034-5.
- Cunha, C. F. R. Da, Goes, L. F. M. "Ensaio de calorimetria e análise termogravimétrica em amostras aleatórias e desconhecidas.", TCC thesis, p. 25–30, 2022.

- Ferreira, I. T. M., Schirmer, W. N., Machado, G. De O., et al. "Estimativa do potencial energético de resíduos celulósicos de fabricação de papel através de análise imediata". *Rev. Gaúcha Odontologia*. [S.l: s.n.], 2014.
- Japan National Municipal Solid Waste Foundation, 1991. *Design Guide for the Facility Solid Waste Disposal*, Tokyo.
- Lemos, C., Cardoso, F., Neumann, F., et al. "Valorização de resíduos oportunidades e desafios", SENAI CETIQT, v. 1990, 2019.
- Lin, C., Chyan J., Chen I., Wang I., "Swift model for a lower heating value prediction based on wet-based physical components of municipal solid waste", *Waste Management* 33 p.268-276, 2013. <<http://dx.doi.org/10.1016/j.wasman.2012.11.003>>
- Nhuchhen, D. R., Abdul Salam, P. "Estimation of higher heating value of biomass from proximate analysis: A new approach", *Fuel*, v. 99, p. 55–63, 2012. DOI: 10.1016/j.fuel.2012.04.015. <<http://dx.doi.org/10.1016/j.fuel.2012.04.015>>
- Nogueira, M. F. M., Rendeiro, G. "Combustão e gasificação de biomassa sólida: soluções energéticas para a Amazônia.", 2008.
- Oliveira, L. Dos S. *Investigação das propriedades físico-químicas e térmicas do caroço de açaí euterpe oleracea para utilização na geração de bioenergia*. TCC thesis. , 2021.
- Parikh, J., Channiwala, S. A., Ghosal, G. K. "A correlation for calculating HHV from proximate analysis of solid fuels", *Fuel*, v. 84, n. 5, p. 487–494, 2005. DOI: 10.1016/j.fuel.2004.10.010.
- Poli, D. De C. R., Zancheta, M. N., Boari, Z. De M., et al. "Uma avaliação das metodologias para determinação do poder calorífico dos resíduos sólidos urbanos", *Revista de Ciências Exatas e Tecnologia*, v. 8, n. 8, p. 9–31, 2014.
- Patermann, C., Aguilar, A. "A bioeconomy for the next decade", *EFB Bioeconomy Journal*, v. 1, n. March, p. 100005, 2021. DOI: 10.1016/j.bioeco.2021.100005. <<https://doi.org/10.1016/j.bioeco.2021.100005>>.
- Sheng, C., Azevedo, J. L. T. "Estimating the higher heating value of biomass fuels from basic analysis data", *Biomass and Bioenergy*, v. 28, n. 5, p. 499–507, 2005. DOI: 10.1016/j.biombioe.2004.11.008.
- Yin, C.-Y. "Unsteady natural convection heat transfer from a heated horizontal circular cylinder to its air-filled coaxial triangular enclosure", *Fuel*, v. 90, n. 3, p. 1128–1132, 2011. DOI: 10.1016/j.fuel.2010.11.031. <<http://dx.doi.org/10.1016/j.fuel.2010.11.031>>.

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