INNOVATIVE ENERGY SOLUTION: SUSTAINABLE ENERGY GENERATION VIA FORESTRY WASTE INCINERATION IN RANKINE CYCLE POWER PLANT

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ABSTRACT

The use of organic solid waste for energy generation has become a promising and sustainable solution to address environmental issues, particularly those related to fossil fuel consumption. Producing energy from forest biomass offers a viable and eco-friendly alternative, aiming to reduce greenhouse gas (GHG) emissions. A key factor for the sustainable production and supply of bioenergy is the abundant availability of suitable raw materials. Among these, forestry pruning waste stands out as a significant resource, often poorly managed and improperly disposed of. An environmentally responsible way to utilize these residues is through incineration, using the resulting hot gases from combustion for energy generation. The primary goal of this study was to quantify the energy generation potential from the forestry pruning waste of UFPR. To achieve this, the organic waste from UFPR was chemically characterized through Proximate Analysis, along with determining the higher heating value and moisture content. A mathematical model was developed to quantify the generation of electrical energy, simulating the steady-state operation of the incineration system. Additionally, a mathematical model of the Rankine cycle plant was created to predict the necessary thermal exchange areas in the plant. The analyses of the collected samples showed heterogeneity, with low ash content at 0.76% and moisture content ranging from 10.67% to 16.80%, but an average high higher heating value of 19.39 MJ.kg-1. The mathematical model predicted that these residues could be sustainably used for electricity generation, with a power output of 54.28 kW. The chemical analysis results led to optimization in the thermal exchange areas of the Rankine cycle plant, facilitating the efficient utilization of hot gases produced from the incineration of these forestry residues.

1. INTRODUCTION

With a burgeoning global population and intensified industrial processes, coupled with escalating energy demands, the world confronts significant environmental challenges, most notably climate change. To address and mitigate these environmental impacts, there is a growing realization of the potential offered by solid vegetable waste as a promising and sustainable energy source. In pursuit of solutions, good environmental practices are being embraced to reduce greenhouse gas (GHG) emissions and minimize detrimental effects on the environment. As an example, recovering the heat produced by burning forest residues. In this context, forest

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residues have emerged as a sustainable alternative with substantial energy value, finding utility in various countries. Forest residues can be utilised with only the need for simple and uncomplicated treatments, varying from case to case, making it a versatile source of energy. Within the framework of the green economy, among other objectives, lies the aspiration to reduce environmental risks and alleviate the scarcity of natural resources, leading to a noteworthy surge in the utilisation of forest biomass for energy generation. Forest residues can be sourced from diverse origins, including natural or planted forests, agriculture, algae, animal waste, and urban refuse, encompassing a broad range of materials such as tree trunks, leaves, branches, pruning residues, grasses, litter, roots, fruits, and others.

The utilisation of forest residues in the production of heat and energy holds the potential to supplant fossil fuels and contribute significantly to the reduction of GHG emissions, thus conferring a substantial environmental advantage. Biomass represents a renewable primary energy source capable of generating thermal energy, electricity, and biofuels. Within this context, forest biomass plays a pivotal role as an energy source, and estimations suggest that it can increasingly contribute to sustainability efforts, resulting in a noteworthy reduction in carbon dioxide (CO_2) emissions compared to reliance on fossil fuels.

Furthermore, there is an upward trend towards employing these forest residues as part of management and conservation strategies. Research indicates that the use of these residues can enhance forest productivity and elevate the value of forested areas. Additionally, they can be effectively utilised for incineration and energy generation, as well as in a biodigester to produce methane, but for this study, the focus of waste utilisation is centred on incineration, due to the subsequent gas treatment. Such practices signify a shift towards more efficient and sustainable management of forest residues, yielding benefits for both the environment and the economy (Vieira et al., 2022; Pena-Vergara et al., 2022; Singh et al., 2022; Gil, 2022).

The incineration of urban solid waste, as well as forest residues represents a thermal treatment process wherein waste is subjected to elevated temperatures for combustion. This method presents a viable solution for managing a diverse array of heterogeneous wastes. Notably, forest residues hold significant potential for generating thermal and/or electrical energy through direct combustion (incineration). Forest residues is gaining interest as a bioenergy feedstock that could avoid competition for land, reduce GHG emissions and contribute to meeting the renewable energy targets of the European Renewable Energy Directive.

This approach allows waste to serve as a valuable raw material source in the energy generation process, yielding both economic and environmental advantages. Incineration has garnered widespread adoption across numerous countries as an alternative for wood and forest residues management, particularly in cases where sufficient physical space for landfills is lacking or when seeking a more efficient averages to harness the energy inherent in waste. Thus, this technique offers a feasible remedy for waste treatment while simultaneously contributing to energy generation (Ribaski and Belini 2019; Corona et al., 2020).

As noted by Tańczuk (2023), many countries still heavily relies on fossil fuels for generating energy to heat its residential districts, with a substantial share of approximately 66% in the energy matrix, while renewable sources, specifically biomass and biofuels, contribute around 25%. As interest in investments in more environmentally friendly and sustainable energy generation systems grows, the exploitation of forest residues emerges as a viable and environmentally friendly option to meet this increasing demand.

According to Cheayb et al. (2023), the use of wood with varying moisture levels proves to be a highly promising alternative for electricity generation in the Rankine cycle, coupled with the practice of cogeneration, in which a portion of turbine gases is directed towards providing heat for industrial processes. This approach significantly contributes to system efficiency enhancement. In Canada the choice of Canadian forest type provides valuable guidance, as indicated in Table 1:

Table 1. Comparison of Wood Fuels for Energy Generation

Type of fuel	**Low heating value (LHV) (MJ/kg)**	**Boiler efficiency**
Dry wood (less than 10% moisture)	18,27	0,84
Wood (45% moisture content)	10,5	0,8

Adapted from CHEAVB et al., 2023.

Finally, in accordance with Aziz, Mudasar, and Kim (2018), the exploitation of forest residues proves highly promising for electricity generation through cogeneration, especially when adopting an organic Rankine cycle. In this system, the working fluid undergoes a transition to superheated steam, with a substantially reduced thermal demand. The author also emphasizes that wood combustion can reach temperatures of up to 1000°C, ensuring the effective operation of this cycle while simultaneously contributing to the reduction of greenhouse gas emissions through the use of renewable energy sources.

In Europe, waste management follows a prioritized sequence that encompasses reduction, reuse, recycling, recovery (including energy recovery), and controlled disposal. Accordingly, it is imperative to prioritize the energy recovery of biomass over landfill disposal to harness its inherent value and recuperate resources. This waste valorization approach represents a sustainable strategy, curbing the volume of waste requiring management and thereby reducing the associated economic expenses and environmental consequences. Nevertheless, incineration with electricity recovery serves as a widely utilised waste disposal and management method in numerous countries. These waste incineration plants are capable of producing marketable electricity, contributing to the mitigation of emissions from fossil fuel-based power plants. GHG emissions can be calculated based on the waste composition slated for incineration. Notably, forest residues, such as wood, feature a biogenic origin for the carbon they contain. Thereby, incineration of materials with biogenic origins is deemed carbon neutral.

Consequently, CO_2 emissions from such materials should not be incorporated in total national emission estimations. Hence, the waste composition stands as a vital factor in estimating the gases produced during the incineration process and their potential subsequent utilisation. It is essential to acknowledge that waste incineration presents challenges and environmental considerations. Particular attention must be directed towards atmospheric pollutant emissions during the incineration process, particularly if the pollution control systems are inadequate. Furthermore, certain waste types may harbor hazardous substances, which could be released into the environment during incineration.

Hence, the adoption of appropriate measures becomes necessary to minimize these adverse impacts and ensure an environmentally responsible waste management approach (Gil, 2022; Zhao et al., 2023). Consonni et al. (2005) carried out a Life Cycle Assessment (LCA) study for different options for recovering energy from residues. They concluded that, due to the emissions avoided from alternative energy production, the greenhouse gas emissions from transforming residues into energy were negative, in other words, reducing overall emissions.

The characterization of forest residues assumes critical importance in determining the optimal technology for their utilisation, refining the combustion process, preempting operational challenges, quantifying the production of hot gases, ensuring environmental integrity, and aligning with regulatory standards. Acquiring comprehensive knowledge of waste properties enables informed decision-making and facilitates the implementation of sustainable approaches for energy generation from these materials. Such characterization significantly contributes to enhancing efficiency, safety, and the utmost exploitation of forest residues as a renewable energy source, thereby fostering responsible resource management (Leme et al., 2021; Aravani et al., 2022).

The generation of hot gases through the incineration of forest residues is a controlled process involving the combustion of these materials to produce heat and energy. The incineration entails the burning of organic components, such as branches, leaves, twigs, and tree trunks, at elevated temperatures (an average of 900oC), resulting in the formation of hot gases. These gases can be effectively utilised for either thermal or electrical energy generation. To harness these hot gases, boiler systems or steam turbines can be employed. Consequently, the hot gases are directed to heat exchanger tubes to heat the water, leading to steam formation, which, in turn, drives turbines for electricity production regulations.

This energy generation process, known as cogeneration or combined heat and power (CHP), is advantageous. However, challenges arise during the incineration of forest residues concerning the quality of the gases and energy efficiency, both of which are contingent on the waste composition. Notably, the moisture content (M) of forest residues significantly influences process energy efficiency. Thus, it becomes imperative to consider pre-treatment techniques such as drying and sorting to optimize combustion and hot gas generation.

Moreover, controlled incineration adhering to environmental regulations is vital to minimize air pollutant emissions. Continuous monitoring of gaseous emissions becomes essential to ensure air quality and compliance with established standards. The incineration of forest residues and the subsequent production of hot gases present an opportunity to efficiently utilise these residues for thermal or electrical energy generation. Advancing technologies and adherence to regulatory guidelines play pivotal roles in the success and viability of this cogeneration system (Danso-Boateng and Achaw, 2022; Bridgwater, 2004; Henne et al., 2019; Galante, 2019).

In order to harness the hot gases produced through waste incineration, it is imperative to ascertain the chemical composition to estimate its quality and regulate process characteristics. The ensuing analysis was conducted to determine the chemical composition, enabling the quantification of constituents like fixed carbon, volatile materials, and ash resulting from the combustion of these residues (Lana et al., 2015; Basu, 2013). Consequently, the primary objective of this research was to quantify the energy production derived from burning forest pruning residues at the Federal University of Paraná (UFPR).

To achieve this, measurements of calorific value (CV), moisture content (M), and proximate analysis were conducted, thus determining the volatile matter (VM), fixed carbon (FC), and ash content of the university's forest residues. Subsequently, a mathematical model was proposed to optimize thermal exchange areas and utilise hot gases for heat cogeneration.

2. METHODOLOGY

A collection of forest residues resulting from the upkeep of the UFPR campuses took place at the designated deposit site, which is situated at the Polytechnic Center campus in Curitiba, Paraná. The specific geographical coordinates for the Polytechnic Center are as follows: Latitude -25.4502422 and Longitude -49.2331921, as shown in Figure 1.

The forest residue samples were obtained directly from the precise location where they were originally disposed of. The collection process involved the extraction of 15 samples, achieved by collecting 5 samples from various segments of the pile, including the top, middle, and bottom sections, as visualized in Figure 2. Following this collection, the samples were mixed, transformed into disc-shaped specimens and subsequently underwent further processing via grinding utilising a hammer mill, with adjustments made to ensure compliance with the NBR 14660 standard specifications.

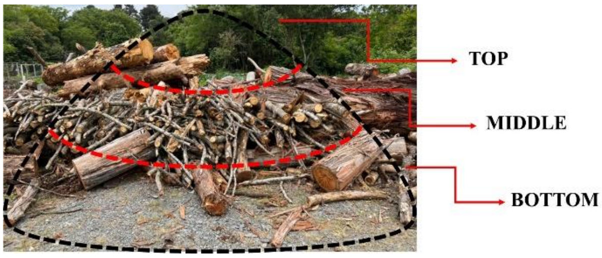

Figure 2. Sample pile of collected forest residues.

The proximate analysis, aimed at determining the levels of volatile matter (VM), fixed carbon (FC), and ash (A), was conducted in compliance with the ASTM D1762-84 standard. The higher heating value (HHV) was ascertained using the IKA C-5000 calorimetric bomb, adhering to the ISO 18125-17 guidelines.

The higher and lower useful calorific values were estimated utilising the 6% hydrogen (H_2) content, commonly employed in biomass, as described by Cortez, Lora, and Gómez in 2008.

Regarding the moisture content of the samples, it was determined following the ASTM D4442-16 standard.

2.1 Mathematical model

The energy balance on permanent regime on incinerator combustion chamber can be described as:

$$0 = \dot{m}_{wood} LHV + \dot{m}_{air} c_{pair} T_{\infty} - (\dot{m}_{air} + \dot{m}_{wood}) c_{pair} T_{inc} \quad (1)$$

where $\dot{m}_{wood}$ is mass flow of wood resides on incinerator (50 kg.$^{-1}$), **LHV** is the lower heating value (dry basis) of wood resides, $\dot{m}_{air}$ is the mass flow of air in incinerator chamber (510 kg.h^{-1}), c_{pair} is the specific heat of air in constant pressure (1 Kj.Kg^{-1}), T_{∞} is the ambient temperature (25°C), T_{inc} is the exit temperature of combustion gases in incinerator calculated by equation 1 (1507°C). The energy balance on boiler of Rankine cycle plant on permanent regime is:

$$0 = (\dot{m}_{air} + \dot{m}_{wood}) c_{pair} (T_{inc} - T_{out}) + \dot{m}_{w} (h_{win} - h_{wout}) \quad (2)$$

where $\dot{m}_{w}$ in the water flow mass in the boiler (kg.h^{-1}, parametric parameter), T_{out} is the exit temperature of combustion gases in boiler (°C, variable) , h_{win} is the enthalpy of water in the center of the boiler (210 kJ.kg^{-1}), h_{wout} is the enthalpy of water in the exit of the boiler (kJ.kg^{-1} calculated). The pressure on boiler was assumed to be 8 bar and the pressure of turbine exit was set to 1 bar.

The model was solved in EES (Engineering Equation Solver) software and the $\dot{m}_{w}$ was parametric varied to calculate the optimum work generated.

Figure 1. Geographic location of UFPR campus

To calculate the isentropic work generated by steam was used the equation below:

$$\dot{W} = \dot{m}_w(h_{wout} - h_{wisoturb}) \quad (3)$$

where $\dot{W}_{iso}$ is the isentropic work generated in turbine (kW) and $h_{wisoturb}$ is the exit enthalpy of steam that exits turbine (kJ.kg^{-1}, calculated based on ideal turbine hypothesis).

With these three equations was possible to find the best water flow mass in the boiler that maximizes the isentropic work generated in turbine.

3. RESULTS

A comprehensive examination was carried out, involving the analysis of fifteen forestry residue samples originating from UFPR, with the primary objective of ascertaining their viability for energy generation. The assessment covered a range of factors, including the results derived from proximate analysis, which encompassed parameters such as FC, VM, and A content. Moreover, moisture **(M)** content and heating values (**HV**) were meticulously assessed, including analyses such as HHV and LHV under both dry basis and received basis variations. Both results were collected and statistically evaluated.

To provide a detailed overview, Table 2 and 3 (see in appendices) furnishes a thorough breakdown of these analyses for each of the fifteen samples under scrutiny.

The moisture content, measured on a wet basis, exhibited a range from 10.67% to 16.80%. This moisture content is considered low concerning the material's suitability for the combustion process (Garcia et al., 2017). The proximate analysis values, FC content ranged from 15.75% to 23.47%. For VM, the variation ranged from 76.10% to 84.08%.

Likewise, the A content samples average from 0.14% to 1.51%, further corroborating the heterogeneity of the samples. It is important to note that the analyzed samples are highly heterogeneous, as evidenced by the elevated coefficient of variation observed for the evaluated properties, as Tukey test results.

These results demonstrate the characteristics of the various species found in the pile of waste collected and analyzed. The ash content found in the analyzed samples was not considered high, as the amount of inorganic minerals does not take part in the combustion process. This substantial variation in ash content may be attributed to the presence of bark material, significantly influencing in the ash content value.

As mentioned by Schirmer et al. (2017), high ash contents have an inverse relationship with HV, potentially leading to a reduction in the biomass's calorific value. Moreover, it was evident that the values for the Proximate analysis (FC, VM, and A), M, and HV align with the findings reported in the literature concerning plant biomass of forest residues (Saccol et al., 2020; Garcia et al., 2017).

As for the HHV on a dry basis, the values ranged from 18.79 MJ.kg^{-1} to 23.68 MJ.kg^{-1}, with an average of 19.39 MJ.kg^{-1}. The LHV on a dry basis displayed values within the range of 17.55 MJ kg^{-1} to 22.44 MJ.kg^{-1}, with an average of 19.17 MJ.kg^{-1}. On the other hand, for the LHV on an as-received basis, the values exhibited variability, ranging from 14.49 MJ.kg^{-1} to 18.63 MJ.kg^{-1}, with an average of 15.91 MJ.kg^{-1}. Notwithstanding the heterogeneity observed in the samples, all the values align with findings reported in existing literature (Brand et al., 2009; Garcia et al., 2017).

Table 2 and 3 displays the average values of the 15 samples, for the mathematical model were used the average values shown in Table 4.

Table 4. Average values from proximate analysis, moisture and heating value (HV) for the analysed samples

Variable	**UNIT**	$\bar{x}$
FC (dry basis)	%	18.78±2.02
VM (dry basis)	%	80.45 ±2.33
A (dry basis)	%	0.76 ± 0.52
M (as received basis)	%	12.88 ±1.77
HHV (dry basis)	MJ.kg^{-1}	19.42
LHV (dry basis)	MJ.kg^{-1}	19.17 ± 1.63
LHV (as received basis)	MJ.kg^{-1}	15.91± 1.35

$\bar{x}$ = average value; average values and standard deviation were expressed on a dry basis.

The average values for proximate analysis were 18.78%, 80.45% and 0.76% for FC, VM and A, respectively. For moisture on a wet basis (as received basis), the average value was 12,88. With regard to the values of higher heating value, lower heating value (on dry basis) and moisture of 12,88% were 19.42, 19.17 e 15.91, respectively.

To quantify the generation of electrical energy, a mathematical model was devised, simulating the steady-state operation of the incineration system, based on the energy and mass balance. Figure 3 illustrates the optimization generated by the proposed mathematical model of the isentropic work generated in the turbine. It is evident that for a wood feed rate of 50 kg.h^{-1}, the optimal water flow mass in the boiler is 0.01575 kg.s^{-1} of steam, equivalent to 56.73 kg.h^{-1} of generated steam. This results in a power output of 54.28 kW.

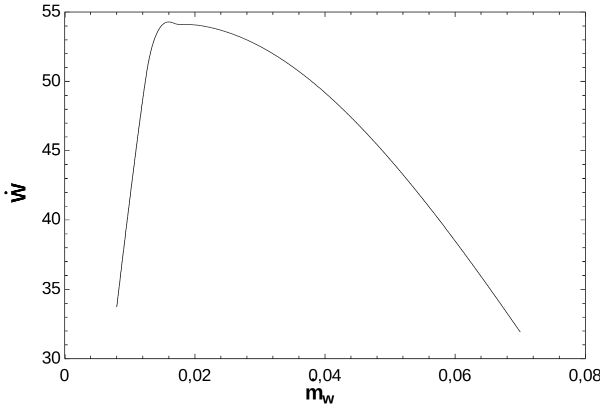

Figure 3. Optimization of isentropic work generated in turbine.

In order to diminish the exploitation of primary resources, forest residues stand as the most preferable option by the recovery and recycling of materials, energy recovery and disposal (landfilling) without recovery. It is clear that the data obtained through the averaging of the 15 samples closely aligns with the data reported on Table 1 by Cheayb et al. (2023). This strongly suggests that the collected forest residues hold substantial potential for electricity generation through the Rankine cycle.

For the same parametric analysis, we can define the cycle efficiency based on variations in water flow. Ultimately, the efficiency calculation relies on the relationship between useful energy, namely, the power generated by the system, in relation to the heat supplied by the boiler. As expected, the cycle's maximum efficiency mirrors the power graph, as illustrated in Figure 4.

When the steam flow is 0.01575 $kg.s^{-1}$, an efficiency of 23.8% is achieved. This value is acceptable for the considered cycle, even though it is relatively low, owing to the use of renewable resources, such as forest residues, which generate energy with reduced greenhouse gas emissions.

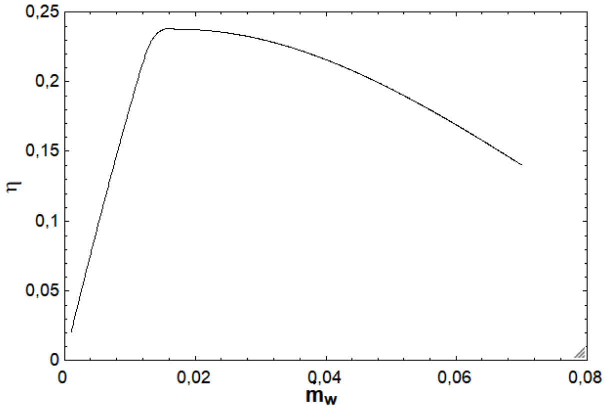

Figure 4. Optimization of efficiency generated on Rankine cycle.

Despite the care taken in sample selection and preparation according to the standards, in some cases, samples may contain different chemical species.

Therefore, even after the normalization process through the calculation of the mean, the ash content may vary due to the presence of barks, which may have varied chemical compositions, as observed in Table 2.

4. FINAL CONSIDERATIONS

In this study, the analyses of the collected samples revealed heterogeneity, indicating low ash and moisture content, but conversely, a high calorific value. The mathematical model, therefore, proposed the use of the hot gases obtained to generate energy, concluding that such utilisation can be carried out efficiently. This opens the door to the application of technologies that can promote a future oriented towards renewable sources as a substitute for fossil fuels. Forest residues have proven to be a viable solid fuel for this purpose.

Furthermore, it was possible to estimate greenhouse gas emissions (GHG) with the utilisation of the hot gases generated from the combustion of forest biomass residues for electricity generation. The mathematical model predicted an optimal electrical power generation of 54.28 kW with the combustion of 50 $kg.h^{-1}$ of forest residues. This illustrates the potential of these residues to be sustainably utilised for electricity generation.

This approach provides an opportunity to optimize the management of forest waste and reduce its disposal in landfills, making it a valuable reference for enhancing waste treatment efficiency and sustainability.

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7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.

8. APPENDICES

Table 2. Results from proximate analysis (FC, VM and A) and moisture (M) for each of the 15 samples.

Sample	**FC (%)**		**VM (%)**		**A (%)**		**M (%)**	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	23.47	±0.21 **a**	76.10	±0.16 **g**	0.43	± 0.06 **e**	15.40	±0.26 **ab**
2	20.16	±0.08 **b**	78.80	±0.12 **e**	1.05	± 0.04 **d**	11.80	±0.25 **cde**
3	17.87	±0.25 **cd**	81.92	±0.25 **bc**	0.21	± 0.00 **f**	12.45	±0.40 **cde**
4	17.26	±0.26 **d**	82.54	±0.26 **b**	0.20	± 0.01 **f**	11.79	±0.38 **cde**
5	18.18	±0.07 **c**	80.50	±0.10 **d**	1.32	± 0.06 **b**	12.82	±0.26 **cde**
6	17.14	±0.43 **de**	82.60	±0.41 **b**	0.26	± 0.02 **f**	11.64	±0.09 **de**
7	15.75	±0.04 **f**	84.08	±0.04 **a**	0.17	± 0.01 **f**	10.67	±0.46 **e**
8	17.19	±0.23 **de**	82.62	±0.21 **a**	0.18	± 0.02 **f**	11.54	±0.64 **de**
9	16.47	±0.37 **ef**	83.40	±0.40 **a**	0.14	± 0.04 **f**	11.26	±0.89 **e**
10	17.31	±0.21 **d**	81.48	±0.24 **c**	1.21	± 0.04 **bc**	13.78	±0.80 **bcd**
11	20.49	±0.11 **b**	77.99	±0.04 **f**	1.51	± 0.11 **a**	14.16	±0.11 **bc**
12	20.15	±0.39 **b**	78.68	±0.35 **ef**	1.17	± 0.05 **cd**	13.96	±0.81 **bcd**
13	20.14	±0.29 **b**	78.72	±0.29 **e**	1.14	± 0.01 **cd**	12.08	±0.67 **cde**
14	19.90	±0.15 **b**	78.90	±0.15 **e**	1.20	± 0.02 **bc**	16.80	±1.84 **a**
15	20.26	±0.17 **b**	78.49	±0.14 **ef**	1.26	± 0.03 **bc**	12.98	±1.69 **bcde**

$\bar{x}$ = average value; **s** = standard derivation; **ar** = as received; **db** = dry basis
Bold lowercase letters followed by the same letter in the column do not differ between the components at a 5% significance level using the Tukey test.

Table 3. Results from heating value (HV) for each of the 15 samples.

Sample	**HHV $_{db}$ (MJ.kg^{-1})**		**LHV $_{db}$ (MJ.kg^{-1})**		**LHV $_{ar}$ (MJ.kg^{-1})**	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	19.42	±0.04 **e**	18.18	±0.04 **e**	15.03	±0.03 **f**
2	19.29	±0.01 **ef**	18.06	±0.01 **ef**	15.65	±0.01 **e**
3	21.16	±0.01 **d**	19.92	±0.01 **d**	16.50	±0.01 **d**
4	21.93	±0.26 **c**	20.70	±0.26 **c**	17.15	±0.22 **c**
5	19.01	±0.02 **ef**	17.77	±0.02 **ef**	14.68	±0.02 **fg**
6	21.27	±0.01 **d**	20.03	±0.01 **d**	16.59	±0.01 **d**
7	23.68	±0.00 **a**	22.44	±0.00 **a**	18.63	±0.00 **a**
8	22.52	±0.36 **b**	21.28	±0.36 **b**	17.65	±0.30 **b**
9	22.63	±0.07 **b**	21.40	±0.07 **b**	17.75	±0.06 **b**
10	18.79	±0.29 **f**	17.55	±0.29 **f**	14.49	±0.25 **g**
11	19.06	±0.02 **ef**	17.82	±0.02 **ef**	14.72	±0.02 **fg**
12	19.05	± 0.09 **ef**	17.82	±0.09 **ef**	14.72	±0.08 **fg**
13	19.45	± 0.00 **e**	18.21	±0.00 **e**	15.05	±0.00 **f**
14	19.45	± 0.06 **e**	18.22	±0.06 **e**	15.05	±0.05 **f**
15	19.37	± 0.03 **e**	18.13	±0.03 **e**	14.98	±0.03 **f**

$\bar{x}$ = average value; **s** = standard derivation; **ar** = as received; **db** = dry basis
Bold lowercase letters followed by the same letter in the column do not differ between the components at a 5% significance level using the Tukey test.