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COMPLETE CHARACTERIZATION OF PRUNING WASTE FROM THE LECHERO TREE (*Euphorbia laurifolia* L.) AS RAW MATERIAL FOR BIOFUEL

B. Velázquez-Martí[1], J. Gaibor-Cházvez[2], Z. Niño-Ruiz[2], S Narbona-Sahuquillo[1]

1) Departamento de Ingeniería Rural y Agroalimentaria. Universitat Politècnica de Valencia. Camino de Vera s/n, 46022 Valencia (España)

2) Centro de Investigación de Ambiente, Departamento de Investigación. Universidad Estatal de Bolívar. Guaranda (Ecuador)

Corresponding author: Borja Velázquez Martí, email: borvemar@dmta.upv.es

Abstract

The aim of this study is to conduct a complete characterization of the pruning waste from the lechero tree. This tree species is of particular relevance in Ecuador for its use as biomass since it yields large amounts of pruning waste, it has a high propagation capacity and very fast growth, for both the trunk and branches. The pruning waste consists of a mixture of wood and leaves, which are subjected to caloric analysis, elemental analysis, proximate analysis, thermogravimetric analysis and fermentability. The average dry pruned biomass obtained per tree is 9.95 kg, with a 1.49 kg standard deviation. The average ratio of leaves in pruned biomass is the 40%. Regression model to determine pruning waste biomass from plant measurements was obtained with 0.7 of r^2. The calorific value of these residues is 19 MJ/kg average. N and ash content is influenced by leaf content. A leaf content less than 25% represent N content lower than 1%, and 6% ash content. Prediction models to higher heat value (kJ/kg) based on elemental, proximate and structural analysis is presented.

Keywords: bioenergy, renewable energy, agricultural biomass

INTRODUCTION

Research on sources of renewable energy has become of great importance in the 21st century since fossil energy (coal, oil, natural gas, etc.) does not comply with the sustainability principles and environmental respect established for the well-being of humanity. Biomass resulting from pruning waste can be used as a source of energy. Several studies have aimed to quantify this resource [1]. However these studies must be supplemented with assessment of the energetic properties of the biomass [2].

The aim of this work has been to assess the waste wood obtained from pruning the lechero tree *(Euphorbia laurifolia* L.*)* cultivated in the Bolivar province, Ecuador. The lechero tree is of particular relevance in Ecuador to be used as biomass due to this tree has traditionally been grown as bushes to define boundary lines between plots, mainly on sloped terrain where cereals are cultivated (mainly corn), as it helps to fix the soil and prevent erosion. It has a high propagation capacity and very fast growth, for both the trunk and branches. Because of this, it is heavily pruned every year in order to avoid excessive growth. This activity produces a great amount of waste material, [3-4]. Up to now the quantification of the amount of available biomass from dendrometry has not been done. This is one of objective of this work.

Besides its use as boundary between plots, the leaves and latex available abundantly in the wood of the lechero have been employed traditionally in medicinal applications [5-6]. The need to fix the soil in order to prevent erosion has led to its widespread cultivation in the Bolivar province.

A complete characterization is a multi-analytical endeavor. The first important parameter is calorific value, the amount of energy released after combustion. The presence of latex in the plant structures could have a significant influence on the energy obtained. To know if the energy is acceptable, it is necessary to perform a dendrometric assessment to calculate the amount of pruning waste available based on the sizes of the plant, such as its height, diameter of the trunk and diameter of the crown. There have been successful results from working with other tree species such as *Plananus hispánica* L. [7], *Sophora Japonica* [8], olive trees [9], almond trees [10], among others. By establishing equations that can determine the total amount of raw materials based on easily measurable variables in the plant, and the energy in them, it is possible to carry out spatial inventories and logistic planning for collection and transportation of the materials. Dendrometric characterization is usually paired with determining the mix percentage of wood and leaves in the raw material, as well as its moisture content.

The elemental analysis is of vital importance as well. This consists of determining the amount of the most important elements present in the material, mainly carbon C, hydrogen H, nitrogen N, oxygen O, sulfur S and chlorine Cl. The content of N, S and Cl is limited by biomass standardization norms because combustion can turn these elements into corrosive acids, damaging thermal installations [11-12].

The C, H, N and O content is used to define the empirical formula for the material and model its complete combustion (Eq. 1). This model makes it possible to calculate the amount of oxygen necessary to achieve this (Eq. 2), and therefore, the amount of stoichiometric air needed (Eq. 3). The relation between the air necessary for complete combustion and the real amount entered into a device is called “excess air parameter”, λ (Eq. 4). If this parameter is bigger than 1, complete combustion will be achieved, if it is smaller than 1, application of heat will result in pyrolysis o carbonization. For this reason, performing an elemental analysis is extremely important [13].

$$\mathrm{CH_w\,O_x\,N_y\,S_z} + n\mathrm{O_2} \rightarrow \mathrm{CO_2} + \frac{w}{2}\mathrm{H_2O} + \mathrm{zSO_2} + \left(\frac{y}{2} + n\frac{79}{21}\right)\mathrm{N_2} \qquad (1)$$

$$\text{Oxygen moles: } n = 1 + \frac{\mathrm{w}}{4} + \mathrm{z} - \frac{\mathrm{x}}{2} \qquad (2)$$

$$\mathrm{Air(m^3N/kg\ of\ biomass)} = \frac{22{,}39\cdot 10^{-3}}{0{,}21}\cdot\left(\frac{m_C}{12{,}011} + \frac{1}{4}\frac{m_H}{1{,}008} + \frac{m_S}{32{,}060} - \frac{m_O}{32{,}000}\right) \qquad (3)$$

$$\lambda = \frac{\text{Required air}}{\text{Stoichiometric air}} \qquad (4)$$

m_C, m_H, m_S y m_O stand for carbon, hydrogen, sulfur and oxygen mass present in the sample, measured as grams for every kilogram of biomass. The denominators correspond to their atomic weight. The N means the volume of air is measured under normal conditions.

In addition to know the amount of air necessary for complete combustion, the carbon content in biofuels is used to calculate the amount of CO_2 previously absorbed by the plant, and consequently, the amount of CO_2 emitted to the atmosphere by its combustion. This way it is possible to know the balance and carry out a carbon footprint analysis.

Other analyses that must be performed during characterization are the proximate and structural analyses. The proximate analysis consists of determining the amount of ash, volatiles and fixed carbon present in the organic matter. The ash is used to estimate the amount of residue to evacuate after combustion; the volatiles to know the mass of gas formed during pyrolysis. Both affect calorific value significantly. The structural analysis consists of determining the amount of lignin, cellulose, hemicellulose and extractives present in the raw material. These structures influence the kinetics of the pyrolysis and possible fermentability [14].

The thermogravimetric analysis is used to study the kinetics of the pyrolysis, according to temperature ramp, type of atmosphere and air flow [15-16].

Fermentation can be an alternative to direct combustion. Microbiologic action decomposes the organic matter into biofuels such as alcohol and methane.

The aim of this study is to conduct a complete characterization of the pruning waste from the lechero tree. The pruning waste consists of a mixture of wood and leaves, which are subjected to caloric analysis, elemental analysis, proximate analysis, thermogravimetric analysis and fermentability.

MATERIALS AND METHODS

Study Area

The study was conducted in the Bolivar province (Ecuador); this province is located in the central area of Ecuador, on the western Andes. Its capital is the city of Guaranda. It is characterized by deep valleys in the high Andes, which serve as agricultural areas. Its climate is subtropical, with a long (May - October) dry season. The land has slopes of 20 to 30%, the temperature oscillates between 6 and 18°C in the highlands, and 18 and 22°C in the subtropic; rainfall is between 500 and 2000 mm.

The lechero tree (*Euphorbia laurifolia* L.), while not exactlu a crop, is widely grown in the area as boundary between plots or fencing for livestock. Its wood is used as raw material for house construction. It also contains latex, which is used as glue as well as plaster. This plant is also used in traditional medicine treatments of liver conditions, infected abscesses and warts. This plant is still given both traditional and ornamental use in the Ecuadorian mountains.

This tree yields large amounts of pruning waste, as it has a high propagation capacity and very fast growth, for both the trunk and branches. Additionally, its location on the periphery of land plots facilitates the extraction and transportation of the residual biomass, as it can be done on the same locations as the pruning.

It is widely distributed in Colombia, Venezuela, Guyana, Ecuador, Peru and Bolivia. In Ecuador it is well represented in every Andean province, from 1500 to 3000 m above sea level.

Depending on handling it is considered either a bush or tree. It has milky latex in its branches and leaves. The inflorescence has five fleshy lobes alternating with glands and some internal bracts. It has several male flowers growing around a single central female flower with pedicels. Its fruits consists of three joined nuts.

Samples were collected in five Andean locations, between 2673 and 2900 m above sea level (Table 1).

Dendrometric analysis

A characterization of the plants, by measuring trunk diameter, crown diameter, height from the crown to the ground, total height of the tree and last year of pruning (Figure 1), was performed before an operator proceeded to prune the trees. Stem and crown diameter (Dt and Dc) was measured with a diameter tape with precision 0.001 m The crown diameter was determined by averaging measurements of the long axis with a diameter taken at right angle. Tree height (H) was determined with a Vertex IV hypsometer with precision 0.01 m. The Vertex IV hypsometer uses ultrasonic pulses together with a transponder fixed to a tree. After pruning, the obtained mass was weighted with a dynamometer, forming sheaves with the woody material. Since pruning was performed while leaves were still on the branches, 5 branches were taken from each tree after pruning and the leaves were removed manually, weighting the branches both before and after removal of the leaves to calculate the percentage of leaf and wood mass. Subsequently, wood samples were taken in plastic containers to determine moisture content via laboratory analysis. Moisture content in the leaves was measured as well. The obtained moisture content value was then used to correct the measured weight and obtain the mass of the dry matter.

The thermochemical characterization of the pruning waste was conducted according to the standardized norms in Table 2. Samples with different percentages of wood and leaf matter were studied: 100% wood, 90% wood/10% leaves, 80% wood/20% leaves, 70% wood/30% leaves, 60% wood/40% leaves, 50% wood/50% leaves, 100% leaves. It is very useful to perform this analysis with different percentages since pruning waste can have different ratios, in turn affecting the final biofuel obtained [7,9,17]

Calorific value

In order to determine calorific value, a portion of the sample, previously dried and crushed, was burned in an LECO AC-500 isoperibolic calorimeter, according to conditions specified in the EN 14918 norm. The sample was placed in a crucible then inserted in a pump with oxygen at 3000 kPa. The pump was entered into the calorimeter in a tray of water, where the temperature was periodically registered. Activation energy was transmitted through a resistance.

Elemental analysis

A Truspec CHN LECO elemental analyzer was used to determine content of carbon, hydrogen, nitrogen and sulfur, in accordance with the EN ISO 16948 norm. The process consists of burning a known mass from the sample in the presence of oxygen, so it turns into ash and gaseous products during combustion. These gaseous products consist mostly of carbon dioxide, water vapor, nitrogen and/or nitrogen oxides, oxides and sulfur oxoacids. These fractions are drawn by helium into different detectors to determine each of the elements.

Proximate analysis

The method used to measure ash content in solid biofuels is specified in EN ISO 18122 norm. The sample used had a minimum mass of 1g, previously kiln dried at 105 ºC for an hour. Once dried, the sample was inserted in the muffle and the temperature was uniformly elevated to 250 ºC for a period of 30 to 50 min (meaning a rise between 4.5 ºC/min y 7.5 ºC/min). This temperature was maintained for 60 min to allow evaporation of volatiles before ignition. Subsequently, the temperature was uniformly raised to (550 ± 10) ºC during a 30 min period, or a rise of 10ºC/min, keeping this temperature for a minimum of 120 min.

Norm EN ISO 18123 specifies the method necessary to determine volatile matter in solid biofuels. Following these specifications, the sample with a minimum mass of 1g was heated in a covered ceramic crucible, out of contact with air, at 900ºC ± 10ºC for 7 min. The percentage of volatile matter was calculated from the loss of mass in the test portion, after deducting mass loss due to moisture content.

For the standard muffle furnace tests, in accordance with EN ISO 18122 norm, the ash content was calculated using equation (5), where m_1 is the crucible and sample mass in grams before heating; m_2 is the crucible and sample mass is grams after heating; $m_{crucible}$ is the mass for the crucible and its lid in grams.

$$\%ash = \frac{m_2 - m_{crucible}}{m_1 - m_{crucible}} \cdot 100 \qquad (5)$$

For the standard muffle furnace tests, in accordance with EN ISO 18123 norm, the volatile matter content was calculated using equation (6), where m_1 is the crucible and sample mass in grams, before heating; m_2 is the crucible and sample mass is grams, after heating; $m_{crucible}$ is the mass for the crucible and its lid in grams.

$$\%volatiles = \frac{m_1 - m_2}{m_1 - m_{crucible}} \cdot 100 \qquad (6)$$

The content of fixed carbon is found by difference, using equation (7).

$$\%fixed\_carbon = 100 - \%volatiles - \%ash \qquad (7)$$

Thermogravimetric analysis

The thermogravimetric analysis evaluates weight loss in the sample as temperature rises in a controlled atmosphere. This analysis was conducted in two different atmospheres: oxidizing (air) and inert (nitrogen). Four different methods were evaluated, with temperature ramps of 25ºC/min and 50ºC/min reaching 550ºC and 900ºC. The analysis was performed in a Mettler Toledo TGA-2 thermogravimetric scale.

Fermentability

The lechero tree is a lignocellulosic material, and so its fermentation requires a microorganism inoculator in order to produce methane. This experiment evaluated methane production resulting from the fermentation of pruning waste from the lechero tree in co-digestion with swine manure obtained from farms in the Guaranda Canton, Bolivar province. The pruning waste was ground to particles smaller than 0.5 mm. A total of 12 repetitions were conducted, with a mixture of 250 g of wood and 100 g of manure diluted to occupy 1 L. Thus, the mixture had a concentration of 0.35 kg of mixture/L. The process was carried out at room temperature varying from 10ºC (nighttime) and 25ºC (daytime).

The experimental device is shown in Figure 2. It consisted of a 2000 ml load-operated vacuum flask, prepared with side outlet, a test tube, a beaker, hoses and rubber stoppers. The produced gases were brought via a hose to an inverted test tube immersed in a beaker filled with water, this made it possible to calculate the volume of biogas by using a volumetric method, according to the shift in distilled water. The percentage of methane was measured by an analyzer in the line. One vacuum flask of 1000 ml with an alkaline solution of sodium hydroxide (NaOH) (5% m/v) and a few drops of phenolphthalein was added. Gases exiting the reactor were passed through it before being taken to the inverted test tube. The carbon dioxide present in the biogas was stopped by bubbling of the biogas [18] in the sodium hydroxide solution. A thermometer was introduced into the mixture to control the temperature. Once the reactor was set, the mixture was placed, the rubber stopper was sealed with silicone and controlled according to the conditions. The use of a CO_2 filter in one of the devices allowed to verify the CH_4 concentration in each treatment.

Chemical oxygen demand (COD), microbial count, pH, total solids and volatile solids were evaluated every 24 hours, over a period of 30 days. Regular measurement of the chemical demand of soluble oxygen (COD) and solids analysis allowed monitoring the biodegradation process of the organic matter [19], while anaerobic biodegradability was analyzed by COD balance of the substrate before and after the anaerobic treatment performed [20]. The methods used are outlined in Table 3.

RESULTS AND DISCUSSION

Dendrometric analysis

The Table 4 shows the statistical summary for each of the variables measured in the dendrometric analysis. $W_{br\ leaves}$ is the biomass in kg per tree of pruned branches with leaves, while W_{br} is the biomass in kg per tree of pruned branches without leaves, Dc is the diameter of the crown in m, Dt is the diameter of the trunk in cm, H is the height of the plant in m and Ht is the height of the trunk

The statistical summary includes parameters of central tendency, variability and shape. The shape parameters, skewness coefficient and standard kurtosis, are especially relevant due to they can be used to determine if the sample comes from normal distribution. Statistical values out of the -2 to +2 range indicate significant deviation from normality, consequently invalidating many of the statistical procedures typically applied to this data. In this case, all the variables are within range, indicating they all have normal distribution.

The trees analyzed have a crown diameter ranging between 0.3 and 5 m, and height ranging from 1.1 to 9 m. The average dry pruned biomass obtained per tree is 9.95 kg, with a 1.49 kg standard deviation, while biomass with no leaves had a dry weight of 5.28 kg, leaf mass meaning approximately 40% of the weight of the pruning waste.

Table 5 shows the Pearson correlation coefficients between variables. These correlation coefficients range from -1 to +1, and measure the strength of the linear relationship between variables. A coefficient close to 1 indicates a direct linear relationship, if a variable increases so will the other. A coefficient close to -1 indicates an inverse linear relationship, when a variable increases the other decreases. A coefficient near 0 indicates there is no relationship between the variables. The asterisk used in the table indicates the estimated correlations are statistically significant, in other words, the relationship has a P-Value inferior to 0.05 and the correlations are significantly different from zero, with a confidence level at 95.0%. It is evident that the dimensions of the plant all have a direct linear relationship, namely, positive values. A bigger trunk diameter implies greater crown diameter and height, with coefficients of 0.52 and 0.61. The weight of the pruning waste increases with crown size as well (r=0.6 and r=0.67). However its relationship with trunk diameter is much weaker (r=0.23 and r=0.29). While the relationship is positive, the diameter of the trunk is a poor indicator of potential obtainable pruning waste.

More than 15 regression models were used to predict waste biomass from dendrometric variables. The model with the highest coefficient of determination resulted from using standardized variables. The standardization of the variables used is shown in equations (8), (9) and (10).

$$H_{nom} = \frac{H - H_{\min}}{H_{\max} - H_{\min}} \tag{8}$$

$$Dc_{nom} = \frac{Dc - Dc_{\min}}{Dc_{\max} - Dc_{\min}} \tag{9}$$

$$Dt_{nom} = \frac{Dt - Dt_{\min}}{Dt_{\max} - Dt_{\min}} \tag{10}$$

The improvement of predictive models to determine pruning waste based on standardized dendrometric variables was previously observed by Velazquez et al., (2016) [22]. These researcher analyzed quantification models of residual biomass from the pruning of orange trees in Bolivar province (Ecuador) based on dimensionless dendrometry. However, the majority of these predictive studies used absolute dimensions, Velazquez y Cazco (2017) [23] and their work with plum trees in Ecuador is an example.

The RMS, 1 kg, is the standard deviation of the difference between the observed values and the ones predicted by the model (Table 6). This value can be used to build limits in further observations. The median absolute error (MAE) of 0.77 kg corresponds to the median value of the deviations mentioned.

Elemental, proximate analysis and high heat value

The means, standard deviation and analysis of variance of the values obtained from the elemental analysis, proximate analysis and calorific value of the different wood and leaf matter mixtures from the pruning waste of the lechero tree are shown in Table 7. The analysis of variance was carried out with a confidence level of 95%. Since the pruning waste is composed of both wood and leaves in varying proportions, it is very important to analyze the mixture. The nitrogen content in the waste material increases significantly with higher leaf percentage. However sulfur content does not vary substantially according to leaf percentage. The value for both N and S is limited in several biomass norms, such as EN ISO 17225-4 (Table 2). The value of nitrogen is greater than 1% when the percentage of leaf matter exceeds 25%. In order not to go over this value, it is necessary to apply separation techniques to the wood and leaves, such as fans after drying.

Leaf presence does not influence calorific value significantly. This value is around 18.5

MJ/kg. It is similar to that of other woody agricultural waste such as orange trees, olive trees, almond trees and vines [10]. It is also similar to that of the 28 materials presented by Channiwala and Parikh (2002) [24], who worked on unified correlation for estimating HHV of solid, liquid and gaseous fuels. They have similar values to those of pruning waste from urban trees, presented in the work of Velazquez et al., (2014) [25]. This means pruning waste from the fig tree, if properly managed, could be introduced to the energy market.

Ash content increases as well according to leaf content (Figure 3). However, the percentage of volatiles percentage was not affected.

The best models to predict calorific value based on elemental (equation 11) and proximate analysis (equation 12) are shown in Table 8. Based on determination coefficient, the models that best explain variability of the calorific value are developed from elemental analysis, with a R^2 of 0.81. However, these are lower than those proposed by other researchers. For example, Pérez et al. (2015) [26] presented calorific value predictive models for 5 species in the Guayas province in Ecuador (banana, avocado, neem, mango, carob trees) with a R^2 of 0.85.

The AIC and BIC statistics make it possible to establish an information criteria based on residual mean square error with a penalty that grows in accordance with the number of coefficients in the model. The aim is to select a model with minimum residual error and as few coefficients as possible.

The ramp from equation 11 indicates that 1% C increases calorific value by 358 kJ/kg.

This value is similar to that obtained by others researchers such as Demirbas y Demirbas (2004) [27] who proposed models for cellulose, hardwood and softwood lignin, beech tree wood and bark, spruce, pine, poplar among many other materials. In all of these, influence of carbon percentage was between 300 and 450 kJ by % C. The same happens in models presented by Sheng and Azevedo (2005) [28], who propose a general biomass model, and Callejón et al. (2011) [29], who introduce models to predict HHV based on the elemental analysis of greenhouse waste.

The influence of volatiles in the models obtained are consistent with that provided by Kathiravale et al., (2003) [30] in his work with urban residues and that of Sheng and Azevedo (2005) [28] and Yin (2011) [31], who worked with biomass in general. However, calorific value prediction models based on proximal analysis are less precise than those obtained from elemental analysis. Callejón et al. (2011) [28] has made the same observation.

Thermogravimetric analysis

Figure 4 shows the drop in weight of the 100% wood sample in relative terms (% of weight) as a function of temperature and time both in the air atmosphere test, without air flow and the nitrogen atmosphere test . It is observed that the profiles obtained for 25 and 50ºC/min temperature ramps are very similar. However, they differ when represented as a function of time. This means the decrease in weight is tied to temperature, regardless of the velocity it is achieved.

As it can be seen, the decrease in weight has got 4 stages. In air atmosphere, first it slowly diminishes until temperature reaches 250ºC. This corresponds at 10 min when 25ºC/min ramp is used, or 5 min when 50ºC/min ramp is used. Subsequently there is a rapid decrease in weight, much more pronounced between 250 y 350ºC. From here on the decrease in weight lessens slightly until reaching residual weight at 18 min when using a 25ºC/min ramp. In nitrogen atmosphere, the profiles has also got 4 stages, but the final mass is higher, due to it corresponds to the char mass and ash mass, while the final mass obtained in heating under air is simply the ash mass. Residual weight when the wood is heated in nitrogen atmosphere is in concordance with shown in Table 7, about 17%. It is reached at 473ºC.

Fermentability

The amount of methane produced by volume and time unit is proportional to the variation of cellular concentration (X). The proportionality constant $Y_{p/x}$ is called *product-biomass performance.*

$$\frac{d[CH_4]}{dt} = Y_{p/x} \cdot \frac{dX}{dt}$$

Given that variation of cellular concentration is proportional to cellular concentration at any given instant, the following applies:

$$\frac{d[CH_4]}{dt} = Y_{p/s} \cdot \mu X$$

The constant μ is the rate of cellular growth. By developing the variation of cellular concentration over time, it is possible to prove that the amount of product obtained (methane) has an exponential growth during the exponential growth of the microorganisms. Consequently, when employing Batch type bioreactors it is best to work during this phase as it has the highest yield. To this end, retention time must be adjusted to the duration of this phase.

$$\frac{dX}{dt} = \mu X \rightarrow \frac{dX}{X} = \mu \cdot dt$$

$$\int_{X_0}^{X} \frac{dX}{X} = \int_{tlag}^{t} \mu \cdot dt$$

$$\ln \frac{X}{X_0} = \mu \cdot \left(t - t_{lag}\right)$$

$$X = X_0 \cdot e^{\mu(t - tlag)}$$

X_0 is the initial cellular concentration in the reactor; X is the cellular concentration at time t, t_{lag} is the lag time or cellular adaptation.

$$\frac{d[CH_4]}{dt} = Y_{p/s} \cdot \mu X_0 \cdot e^{\mu(t - tlag)}$$

$$[CH_4] = Y_{p/s} \cdot X_0 \cdot \left(e^{\mu(t - tlag)} - 1\right)$$

Since the value of $Y_{p/s} \cdot X_0$ is negligible compared to the exponential $Y_{p/s} \cdot X_0 <<< Y_{p/s} \cdot X_0 \cdot e^{\mu(t - tlag)}$, it is possible to graph the accumulated volume obtained, calculating cellular growth rate, substrate productivity, and optimal retention time for better energy use.

$$[CH_4] = Y_{p/s} \cdot X_0 \cdot e^{\mu(t - tlag)} \qquad (11)$$

The model obtained from the experiments (Eq. 11) is shown in Figure 5. The different point shape allows to differenciate the exponential production of CH_4 and the stationary phase where the production of methae in very low. Exponential model of first phase gave determination coefficients (r^2) between 0.85 and 0.99 in every repetition, which explains variability in methane production per unit between 85 and 99%. The rate of cellular growth has an aggregated mean value of 0.76 6 day^{-1}. The saturation constant Ks was 0.0015 g L^{-1}, and 1/Y average was 253 g COD removal/g SSV.

CONCLUSIONS

This research has shown it is possible to develop acceptable models to predict pruning waste from the *Euphorbia laurifolia* in Bolivar province weather, Ecuador.

The average amount of material obtained per tree is around 10 kg every year. The calorific value of these residues is consistent with that of other tree species, with a mean of 19 MJ/kg.

The pruning waste's N content is influenced by leaf content. If leaf content is less than 25%, N content will be less than 1%. This means the material is suitable to be used as biofuel.

It is demonstrated that leaf matter affects ash content, nevertheless the change in calorific content is small and not measurable with the uncertainty in the method, or it could be the case that the chemical composition of the leaf offsets the displacing effect of the ash.

It was proved possible to predict calorific value based on elemental and proximate analyses.

Weight variation of wood and leaf mixtures of *Euphorbia lancifolia* was analyzed in a thermogravimetric scale (TGA). The results indicate residual weights after using 25ºC/min and 50ºC/min ramps up to 550ºC and 900ºC do not evidence significant differences from those obtained with standardized methods EN ISO 18122 to obtain ash content and EN ISO 18122 to obtain volatile content. It also seems decrease in weight is tied to temperature, regardless of the rate it is achieved at.

The fermentation productivity of lechero wood and swine manure mixtures was proven, determining the kynetic constants.

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Table 1. Location of cities where samples were collected

Location	X-UTM	Y-UTM	Number of sampled trees
Casipamba	0724310	9823619	40
Cuatro Esquinas	0703282	9831110	40
San Simon	0722484	9820762	40
Las Conchas	0725105	9828657	40
Negroyaco	0722596	9826577	40

Table 2. Biomass characterization analysis norms

Norm Reference	Title
EN ISO 16559	Solid biofuels – Terminology, definitions and descriptions
EN 14778	Solid biofuels – Sampling – Part 1: Sampling methods
EN 14780	Solid biofuels – Methods for sample preparation
EN ISO 18134-2	Solid biofuels – Determination of moisture content – Kiln drying method. Part 2. Simplified method: moisture total.
EN 14918	Solid biofuels – Determination of calorific value
EN ISO 18123	Solid biofuels – Determination of volatile matter content
EN ISO 18122	Solid biofuels – Determination of ash content
EN ISO 16948	Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen – Instrumental methods
EN ISO 16994	Solid biofuels – Determination of total content of sulfur and chlorine.
EN ISO 16993	Solid biofuels – Calculation of the analyses to different bases
EN ISO 17225-1	Solid biofuels – Specifications of biofuel and classes – Parte 1: General requirements
EN ISO 17225-4	Solid Biofuels. Fuel specifications and Classes. Part 4: Wood chips.

Table 3. Methods used in determining the physico-chemical parameters

Parameters	Standard method / technique *
Total Solids (TS)	Gravimetric method - APHA / SM 2540-B [21]
Volatile solids (VS)	Gravimetric method - APHA / SM 2540-B [21]
COD	5220-C standardized method (Spectrophotometer Hach DR 2800, HACH digester DRB 200)
pH	Potentiometric method, digital pH meter (HACH HQ40d Potentiometer)
Volume of methane	Volumetric method (NaOH 5%)
Volume of biogas	Volumetric method (Distilled Water)

Tabla 4. Statistical summary of variables measured in the dendrometric analysis

	Dc (m)	Dt (cm)	H (m)	Ht (cm)	$W_{br\ leaves}$ (kg/tree)	W_{br} (kg/tree)
Average	1.41	12.86	3.10	12.14	9.95	5.28
Standard deviation	0.69	7.18	1.21	12.55	1.49	1.17
Minimum	0.3	3.5	1.1	0.16	2.24	1.06
Maximum	5.0	48.38	9.0	55.0	10.3	5.15
Standard skewness	1.83	1.77	1.06	1.46	1.02	1.09
Standard kurtosis	1.49	1.17	1.92	-1.01	-1.22	-1.54

Table 5 Pearson correlation coefficients between the variables measured

	Dc (m)	Dt (cm)	H (m)	Ht (cm)	$W_{br\ leaves}$ (kg/tree)	W_{br} (kg/tree)
Dc (m)		0.5218*	0.7580*	-0.3786	0.6005*	0.6747*
Dt (cm)	0.5218*		0.6186*	-0.1560	0.2303	0.2914
H (m)	0.7580*	0.6186		-0.3535	0.1443	0.2262
Ht (cm)	-0.3786*	-0.1560	-0.3535		0.3474	0.2973
$W_{br\ leaves}$ (kg/tree)	0.6005*	0.2303	0.1443	0.3474		0.9723*
$W_{br\ leaves}$ (kg/tree)	0.6747*	0.2914	0.2262	0.2973	0.9723*	

Table 6. Regression model to determine pruning waste biomass from plant measurements

Regression model	**R^2**	**$R^2_{adjusted}$**	**RMS**	**MAE**
W_{br} (kg/tree) = 2.50+ 6.31*Dcnom -14.99*Hnom*Dcnom +6.78*Dtnom	**0.70**	0.68	0.99	0.77

Table 7. Means and standard deviations of values obtained in the elemental analysis, proximate analysis, and high heat value

Leaves	% N	*% C*	*% H*	%S	% Ash	% Volatiles	% Fixed Carbon	HHV (MJ/kg)
0	0.51±0.065 a	44.97±0.40 a	4.58±0,057 a	0.42±0.310 a	3.70±0.04 a	82.92±2.04 a	13.38±2.00 a	18.64±0.56 a
10	0.80±0.018 b	45.00±0.21 a	4.60±0,051 a	0.16±0.050 a	4.95±0.07 b	84.21±0.58 a	10.84±0.56 a	18.54±0.64 a
20	0.88±0.031 c	44.86±0.32 a	4.54±0,065 a	0.09±0.018 a	5.19±0.11 c	79.48±2.66 a	15.33±2.67 a	18.46±0.42 a
30	1.15±0.045 d	44.96±0.35 a	4.54±0,091 a	0.06±0.015 a	6.17±0.14 d	78.85±0.53 a	14.97±0.39 a	18.31±0.29 a
40	1.28±0.033 e	44.83±0.81 a	4.55±0,091 a	0.06±0.011 a	6.50±0.06 e	85.27±9.42 a	8.23±9.48 a	18.61±0.27 a
50	1.62±0.039 f	44.61±0.51 a	4.44±0,036 a	0.06±0.005 a	7.30±0.07 f	76.27±3.90 a	16.44±3.92 a	18.56±0.34 a
100	2.51±0.017 g	45.46±0.29 a	4.38±0,105 a	0.07±0.016 a	10.37±0.17 g	75.75±0.07 a	13.88±0.22 a	18.68±0.07 a
Total	1.25±0.622 h	44.95±0.48 a	4.52±0,101 a	0.13±0.164 a	6.31±2.03 h	80.39±4.91 a	13.30±4.36 a	18.54±0.36 a

Table 8. Prediction models to calculate calorific value (kJ/kg) based on elemental, proximate and structural analysis

Eq	**Regression models**	**R^2**	**R^2_{aj}**	**RMS**	**MAE**	**AIC**	**BIC**
11	HHV = 2.41181 + 0.358645*C (%)	0.81	0.70	109.07	64.02	9.70	9.67
12	HHV = -25.8414 + 7.20071*%Ash – 0.0679335*%Ash^2 + 0.519929*% Volatiles – 0.0792363*% Volatiles*%Ash	0.75	0.62	128.06	97.45	11.07	11.05

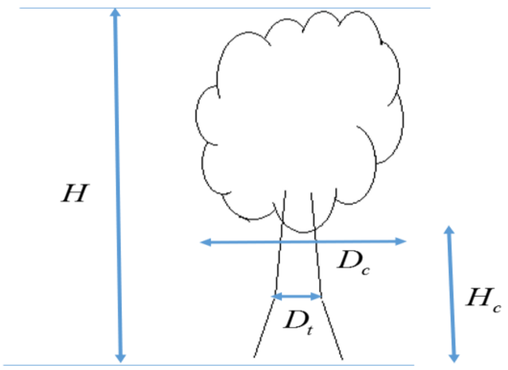


Figure 1. Geometric measurement of the tree

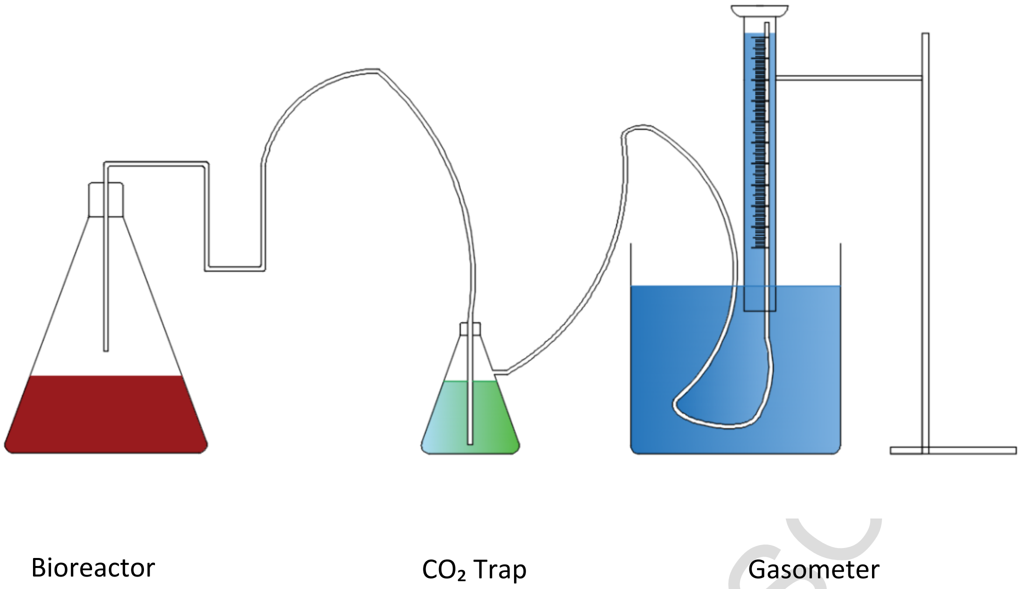
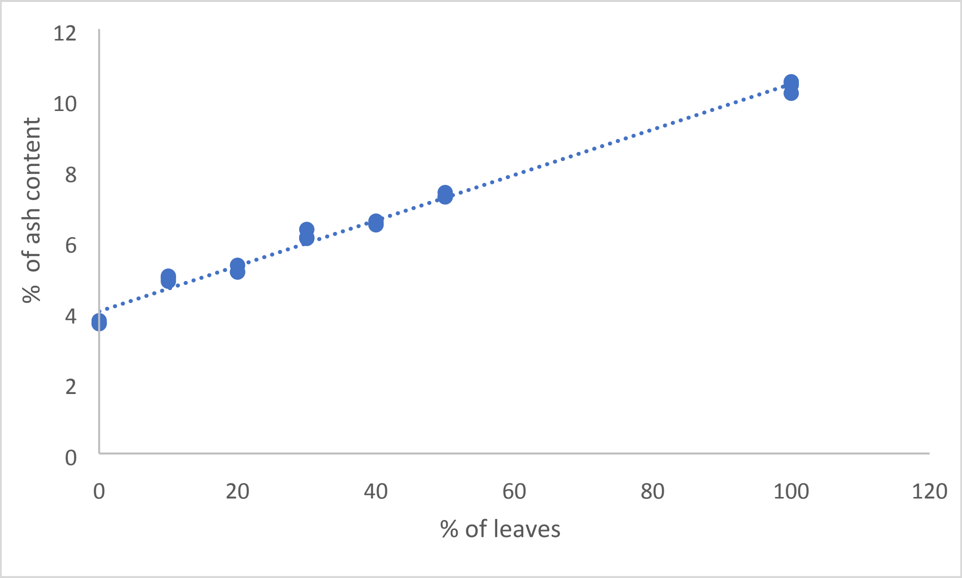


Figure 2. Diagram of the experiment



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649 Figure 3. Ash content according to percentage of leaves

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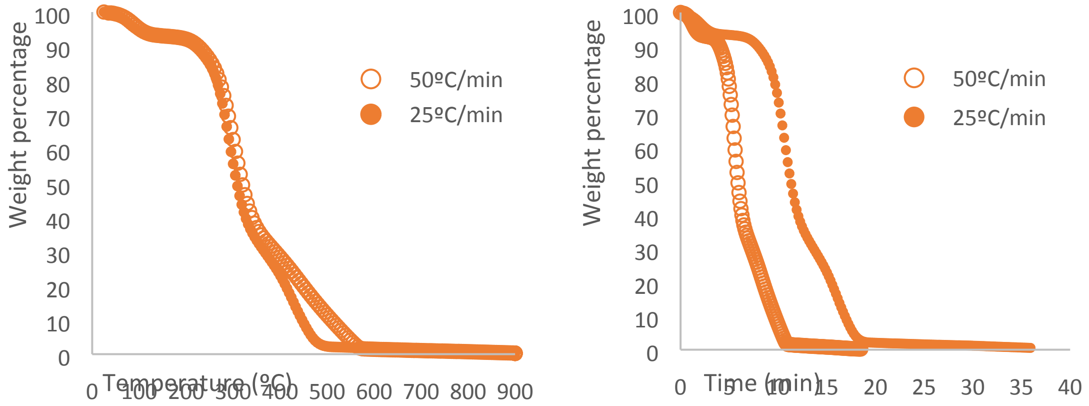
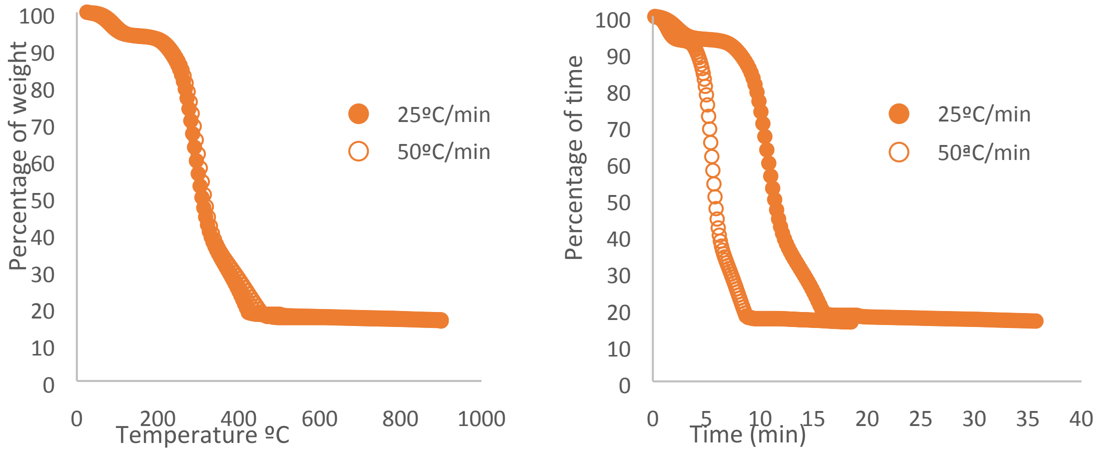


Air atmosphere



Nitrogen atmosphere

Figure 4. Variation of the weight percentage of the sample versus temperature and time in different atmospheres.

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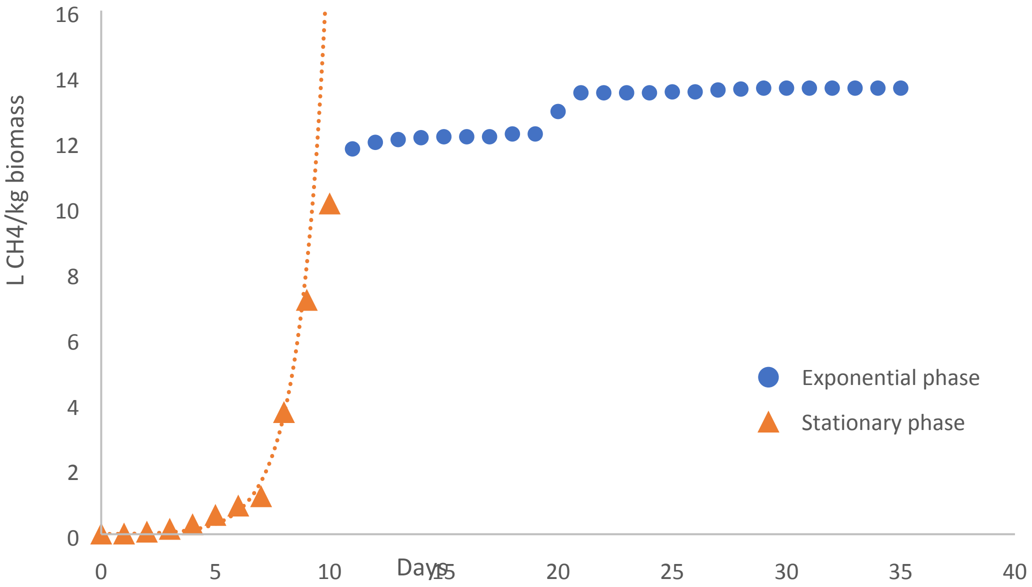

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661 Figure 5. Accumulated CH_4 per kg of substrate

Highlights

- Dendrometric analysis has been carried out of *lechero tree* of Ecuador.
- It has become the elemental, proximate and structural analysis
- Models for predicting higher calorific have been evaluated.