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Energy content of *Eucalyptus* hybrid clones, developed by INTA

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Abstract

This work focuses on determining the energy content of two Eucalyptus hybrid clones developed by INTA. The general objective is to determine the lower and higher heating value of these clones, generating accessible information on the use of lignocellulosic materials as an energy source. The results revealed that both hybrid clones have potential as biomass for energy use, being attractive as fuels. The GC INTA 27 hybrid clone showed an average higher heating value of 4247.15 cal g-1, while the GC INTA 24 clone presented an average value of 4192.47 cal g-1. Statistical analysis showed that there were no significant differences between the two clones in terms of heating value. In addition, the values obtained with similar studies in the genus Eucalyptus were compared, observing similarities in the thermal properties. In conclusion, this study shows that the evaluated hybrid clones are a promising source of biomass for fuel use. The results are consistent with previous research in the same botanical genus and suggest the possibility of relating the heating value data with other properties such as density, moisture, and fixed carbon, for a more complete evaluation of the energy potential of these materials.

Key words: Heating Value; Biomass; Energy.

Introduction

Regulations on renewable energy in Argentina mandate an increase in electricity generation from alternative sources. These energies are derived from natural resources and produce lower levels of greenhouse gas emissions compared to fossil fuels. Biomass belongs to this group, and its applications include both thermal and electrical uses (GRIFFA *et al*., 2018). At present, it is experiencing significant growth and represents a source of energy that enables the reuse of residual materials, particularly organic matter (Hernández Tavico, 2018).

In renewable energy projects, biomass technologies cannot be considered exclusive to electricity generation. The national initiative PROBIOMASA (Project for the Promotion of Biomass-Derived Energy) also encompasses the production of thermal energy, drawing on the extensive availability of biomass resources across the country to provide a clean, reliable, and competitive energy supply. Heat generation from biomass ranges from the burning of wood in domestic settings to combustion at industrial scales. Furthermore, energy generation from biomass has a limited global distribution and is more commonly employed in facilities within industrial complexes, which obtain said fuel through their own internal production processes (FAO, 2020).

According to Sánchez Acosta (2016), these plantations are being promoted as a viable alternative to partially replace timber sourced from native forests, with the aim of reducing indiscriminate logging. This transition seeks to enable a more efficient and controlled use of forest resources, fostering sustainable management that preserves biodiversity while meeting the demand for wood-derived products, including those intended for energy or industrial applications.

In Argentina, the energy matrix relied on fossil fuels for 87% of its supply, while bioenergy accounted for only 6.1% in 2020 (FAO, 2020). Within this latter share, the residues produced by the forestry sector hold significant potential as biomass for bioenergy production. However, by 2021, only 11% of the energy consumed came from renewable sources (Kloster, 2021), reflecting a slight improvement compared to the previous year, yet still insufficient in view of the need to increase the share of sustainable sources in the national energy matrix.

Approximately 11% of global primary energy consumption comes from biomass, most of which is directly obtained from wood or from residues generated by industrial processes. Globally, Brazil is one of the largest producers of low-cost, high-productivity forest products and is also the second country in the world with the largest area of eucalyptus reforestation (Menucelli et al., 2019).

Cloning is the most effective means of improving genetics, since the selection of genetic material makes it possible to establish homogeneity, given that genetic variation among plants is considerably low. By mixing genetic materials, various benefits can be obtained, such as greater tolerance, reduced competition, and higher yields (Olguín et al., 2009). Hybridization is a genetic improvement process aimed at obtaining one or more superior traits, with the main objectives being increased productivity and the enhancement of factors that determine the quality of the output (Sánchez Acosta, 2012).

“Forests in Argentina are composed primarily of conifers (66%), followed by eucalyptus (24%), salicaceous species (7%), and others (3%).” In the forestry industry—particularly in the primary processing chain—residues account for more than 50% of the initial volume entering the process. These residues could be used as fuel while also generating added value through by-products (FAO, 2019). Argentina is an emerging country with diverse opportunities for the production of forest products. One of the most well-known and widely used species is

Eucalyptus grandis, with more than 200,000 hectares of forest plantations across the provinces of Entre Ríos, Corrientes, and Misiones (Sánchez Acosta, 2012).

It is important to select the appropriate wood to be used as raw material for bioenergy production (Menucelli et al., 2019). Rocha et al. (2016) reports that the establishment of forests for energy use encourages forestry industries to select raw materials with suitable properties to improve product quality, thereby increasing the energy efficiency of forests and reducing costs. Their study shows that the use of denser wood results in denser charcoal, which can be achieved by increasing plant spacing. For example, in hybrid eucalyptus clones planted at spacings ranging from 3 m × 1.5 m to 3 m × 3 m, a wood density of 0,55 g cm-3, 8% was obtained—8% higher than that of plantations with shorter spacing.

The objective of this study was to determine the heating value of two hybrid eucalyptus clones in order to provide the industrial sector with essential information regarding their energy contribution, as well as insights into their characteristics for use in genetic improvement programs within the renewable energy generation market. The null hypothesis states that there are no significant differences in heating value between the two clones evaluated.

Materials and Methods

This study was carried out within the framework of the research project "Physical characteristics and absorption capacity of wood from pure and hybrid clones of Eucalyptus grandis and E. grandis × E. Camaldulensis originating from two geographic regions" (Suirezs et al., 2021), Code 16/F1338-PI.

At the time of sampling, the genetic materials were 15 years old and were part of the clone trial network of INTA's (National Institute of Agricultural Technology) eucalyptus breeding program. These materials are registered in both the National Cultivar Registry and the National Registry of Cultivar Ownership of INASE (National Seed Institute). For the study, eight trees were considered for each genetic material. From each tree, multiple test specimens were obtained, ensuring a representative sample per tree and a total number of specimens exceeding the minimum requirements established by ASTM Standard No. 143/52.

The material used corresponded to clone trees obtained from a trial located at the premises of the INTA Concordia Agricultural Experimental Station (EEA), Yuquerí Station, at Provincial Route 22 and the railway tracks, Concordia Department, Entre Ríos. The plantation was established within the following GPS coordinates: longitude 58°07'16" W, latitude 31°21'56" S, and elevation 47 m a.s.l., with a spacing of 3.5 m × 3.5 m. It consisted of linear plots of five

plants oriented north to south. The site has sandy loam soil and a gently undulating geography.

To determine the heating value of the wood, samples were taken from the two hybrid materials under study, Eucalyptus grandis × E. camaldulensis, with five repetitions performed for each material. Specialized equipment was used for the determination of heating value, including a muffle furnace, a Parr® Instrument Company calorimeter bomb model 1341 (comprising a stirrer, stirrer motor, water vessel, and insulated bucket), an oxygen cylinder at 25 atm, a precision thermometer graduated to 0.2 °C, and an ignition wire. In addition, materials such as water, benzoic acid tablets, absorbent paper, and the test material (in the form of compressed tablets) were employed.

Procedure

The tests were carried out in the Wood Technology Laboratory (IMAM) of the Faculty of Forestry Sciences (UNaM), Eldorado Regional Campus, following the procedure established by IRAM Standard 17016 (1960).

Calibration of the calorimeter bomb (Figure 1) was performed using a 1-gram benzoic acid tablet with a known heating value (6,318 cal g-1), and the temperature difference was measured during combustion.

Subsequently, the heating value tests of the materials under study were conducted.

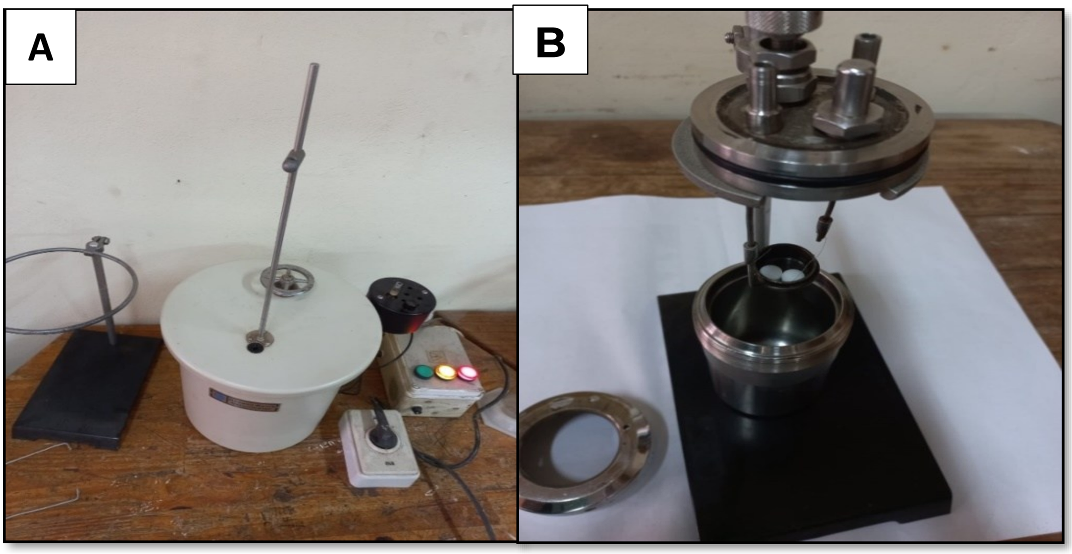

Figure 1. a) Parr® Model 1341 Calorimeter Bomb and b) Benzoic acid tablets for calibration

The sequence of the tests initially consisted of taking 1 to 1.5 g of fuel, previously ground and dried, which was then formed into a circular tablet and placed in the crucible of the bomb.

The ignition wire, cut to a length of 10 to 15 cm, was connected to the electrodes of the calorimeter bomb. Once the electrodes were connected, the bomb was sealed and pressurized with oxygen at 20–25 atm. The water vessel inside the insulated bucket was filled with 2,000 g of water. The pressurized bomb was then placed in the vessel, and the electrical leads connected. The lid of the adiabatic jacket was closed, and the stirrer motor was turned on to homogenize the water temperature. The thermometer was inserted into the adiabatic jacket and allowed to stabilize, at which point the reading was recorded as the "Initial Temperature".

The switch was then activated to initiate the combustion process. Once the temperature stabilized, it was recorded as "Final Temperature".

Once the final temperature was reached, the bomb was removed from the adiabatic jacket, and the pressure was completely released. The amount of water remaining inside the bomb was determined by weight difference, and the length of the unburned ignition wire was measured. Both data were necessary for the subsequent calculations.

- *Determination of the Higher Calorific Value*

The Higher Heating Value (HCV) is defined under the assumption that all elements of combustion (fuel and air) are taken at 0 °C and that the products (combustion gases) are also cooled to 0 °C after combustion, so that the water vapor is fully condensed. Equation No. 1, with the respective units used for the calculations, is presented as follows:

$$PCS = \frac{Ca.(K+ma).(tf-ti)-Ch.(Li-Lf)}{G}\left[\frac{cal}{g}\right] \qquad 1$$

- *Determination of the Lower Calorific Value*

The Lower Heating Value (LCV) assumes that the water vapor contained in the combustion gases does not condense. Therefore, there is no additional heat contribution from the condensation of water vapor. Only the heat of oxidation of the fuel is available, which by definition is referred to as the Lower Heating Value of the Fuel (LCV). Equation No. 2, used for the calculations, is presented as follows:

$$PCI = \frac{Ca.(K+ma).(tf-ti)-Ch.(Li-Lf)}{G} - \frac{r.g}{G}\left[\frac{cal}{g}\right] \qquad 2$$

Where:

K: [g] Constant of the calorimeter bomb.

ma: [g] mass of the water in the vessel.

Ca: [cal g^{-1} °C^{-1}] specific heat of water.

G: [g] mass of the fuel.

ti: [°C] initial temperature.

tf: [°C] final temperature indicated by the thermometer.

Li: [cm] initial length of the ignition wire**.**

Lf: [cm] final length of the ignition wire.

Ch: 2,3 [cal cm^{-1}] heat released by the ignition wire.

g: [g] mass of condensed water.

r = 597 [cal g^{-1}] total heat of vaporization of water from the liquid state at the initial temperature.

Ca: 1 [cal g^{-1} °C^{-1}] specific heat of water

To assess potential differences between the variable values across clones, a comparative analysis of the mean was carried out using the statistical package Infostat® (2020). Additionally, descriptive statistics were applied to the heating value data (HCV and LCV).

Results and Discussion

According to the descriptive statistics applied to each hybrid clone, it was determined that the genetic material GC 27 presents a heating value (CV) 1.3% higher than that of clone GC 24.

Table 1. Calorific Value of Eucalyptus Hybrid Clones

Clones	Variable	n	Mean [cal g^{-1}]	D.E.	CV	Min. [cal g^{-1}]	Max. [cal g^{-1}]
GC INTA 24	HCV	5	4,192.47	128.79	3.07	3,968.71	4,286.06
GC INTA 24	LCV	5	3,855.77	130.88	3.39	3,628.42	3,957.71
GC INTA 27	HCV	5	4,247.15	107.36	2.53	4,155.53	4,431.85
GC INTA 27	LCV	5	3,904.47	110.02	2.82	3,821.21	4,091.56

According to Table 1, the LCV ranged from 3,855.77 to 3,904.47 cal g-1, while the HCV of the hybrid clones ranged from 4,192.47 to 4,247.15 cal g-1. The coefficients of variation provide an indication of the relative variability in the data, whereas the means, standard deviations, and maximum and minimum values describe the central tendencies and dispersion characteristics in each case. The hybrid clone with the highest heating value was GC INTA 27, which also showed the lowest data variability.

Table 2. Comparison of Means by Student t test

Variable	Group 1	Group 2	n1	n2	Mean 1 [cal g^{-1}]	Mean 2 [cal g^{-1}]	Var. 1	Var. 2	p-Hom Var	t	p	Test
HCV	GC24	GC27	5	5	4,192.47	4,247.15	16,586.59	11,526.70	0.7329	0.73	0.4867	Bilateral
LCV	GC24	GC27	5	5	3,855.77	3,904.47	17,129.53	12,103.65	0.7447	0.64	0.5420	Bilateral

Table 2 shows the results of an independent samples t-test comparing GC24 and GC27 in terms of the HCV and LCV variables, with a sample size of 5 for each group, along with other statistical data.

Regarding HHV, the mean difference between the groups was 54.67, with an associated t value of 0.73 and a p-value of 0.48. For LHV, the mean difference was 48.7, with an associated t value of 0.64 and a p-value of 0.542. In both cases, the results indicate homogeneity of variances, as can be observed in Figure 2.

In summary, the p-values are relatively high (greater than 0.05), suggesting that there is insufficient evidence to reject the null hypothesis that the means of both groups are equal. In other words, there are no statistically significant differences between the groups in terms of the HCV and LCV variables.

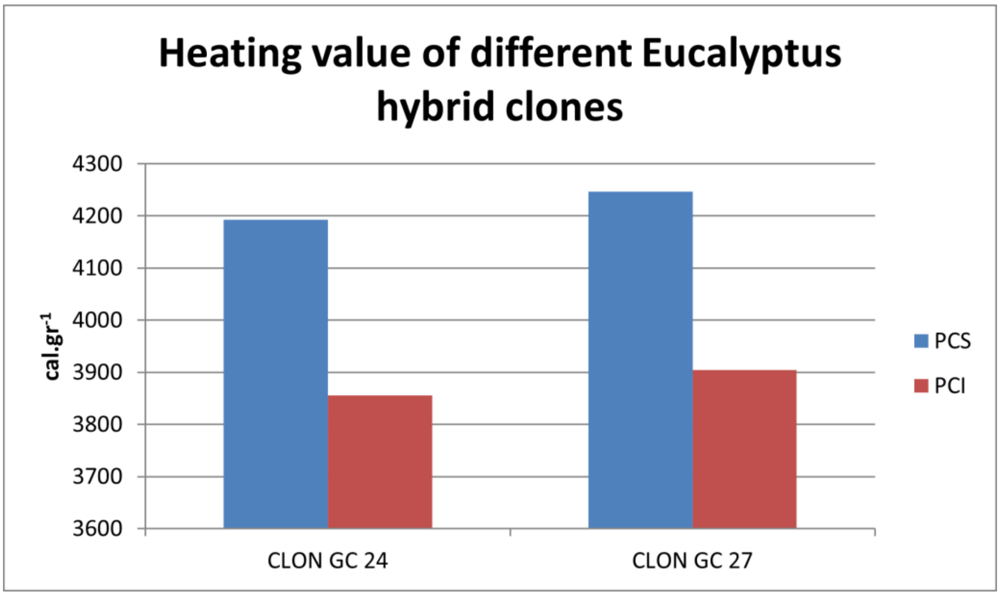

Figure 2. Average heating value

Comparable values have been reported in similar studies within the genus *Eucalyptus*. Figueredo et al. (2019), working with *Eucalyptus grandis*, found LCV and HCV values of 3,856 cal g-1 and 4,140 cal g-1, respectively. In contrast, Gauna et al. (2022), evaluating the same materials (GC 27 and GC 24) at the age of 7 years, obtained a HCV of 4,650 cal g-1, which is higher than that observed hereby. Magalhães et al. (2017) assessed 7-year-old *Eucalyptus urophylla* × *Eucalyptus grandis* clones and reported mean HCV values of 4,466 cal g-1. Such heating values and their similarities may be influenced by factors related to wood composition, such as carbon, lignin, hydrogen, and extractives, which are known to have a positive effect on this variable (Simetti et al., 2018; Magalhães et al., 2017).

Conclusion

This study aimed to determine the heating value of two hybrid clones obtained by crossing *E. grandis* × *E. camaldulensis* (GC), namely GC INTA 27 and GC INTA 24. Heating value is an important property, as it defines the potential of wood as an energy biomass.

The results indicate that the evaluated hybrid clones represent an attractive biomass source for fuel use. Among them, GC 27 showed the highest heating value, with 4,337.0 cal g-1, compared to 4,192.4 cal g-1 in GC 24.

The heating value results of the evaluated materials were consistent with those reported in other studies on this botanical genus. Although the values for both clones were quite similar, it is strongly advised to increase the number of samples and variables to better understand and corroborate the results obtained.

The results of this study are encouraging and open the possibility of exploring relationships between the Higher Heating value (HCV), the Lower Heating value (LCV), and density. Although such a relationship is not conclusively established here, the combined analysis of moisture content and fixed carbon provides useful information for the thermal characterization of these hybrid clones. In this regard, Pereira et al. (2013) found that higher basic density in *Eucalyptus* tends to be associated with a greater fixed carbon content, which in turn influences the charcoal's heating value. This line of research could enrich future assessments of wood fuel potential for both domestic and industrial applications.

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