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ANALYSIS OF THE CALORIFIC VALUE OF *EUCALYPTUS GLOBULUS* LABILL AND *PIPTOCOMA DISCOLOR* (KUNTH) PRUSKI FOR CHARCOAL PRODUCTION IN THE ANDES OF ECUADOR

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Summary

The objective of this work was to analyze the calorific value of Eucalyptus globulus and Piptocoma discolor in wood and charcoal in the Chimborazo Province. The standards of the Ecuadorian Institute for Standardization (INEN) and the American Society for Testing and Materials (ASTM) International were used for the laboratory analyzes of wood density, volume, biomass, volatile material, ash percentage and calorific value. For this, 5 samples of wood and charcoal were used for each species. For the statistical analysis of the data, the theoretical assumptions of normality and homoscedasticity were verified and comparison tests were used for two independent samples with the statistical package IBM-SPSS 25.0. The results obtained were: Eucalyptus globulus 43.88% (wood moisture), 11.43% (charcoal moisture), 0.96 g/cm³ (green wood density), 0.82 g/c m³ (dry wood density), 0.36 g/cm³ (charcoal density), 1064.13 kcal/kg (wood calorific value), 6719.79 kcal/kg (coal calorific value) while Piptocoma discolor: 43.88% (wood moisture), 59 .38% (charcoal moisture), 0.85 g/cm³ (green wood density), 0.56 g/cm³ (green wood density), 0.32 g/cm³ (charcoal density), 804.61 kcal/kg (wood calorific value), 2604.01 kcal/kg (coal calorific value). It is concluded that the highest efficiency of calorific power in kcal/kg was obtained for Eucalyptus globulus both in charcoal and wood.

Keywords: density, volatile material, ash content, carbon, wood

Introduction

It is considered that sixty percent of all wood extracted in the world is burned as fuel, either directly, or transformed into charcoal. The proportion of firewood used for the manufacture of charcoal can be estimated, around 25 percent of the amount mentioned above, that is, about 400 million cubic meters per year (Rosero and Cabrera 2014).

Charcoal, in developing countries, is mainly used as a domestic fuel, for cooking and heating, but it is also an important industrial fuel. Large quantities are used in foundries and forgings; in the extraction and refining of metals, especially iron, and in numerous other metallurgical and chemical applications. For developing countries, abundantly endowed with forests, the export of charcoal can be a profitable industry (Rosero and Cabrera, 2014).

The energy availability of different renewable energy sources (hydroelectric, wind, solar, biomass, etc. They are larger than conventional energy sources (oil, gas, coal, etc.); However, the use of renewable energies is scarce. The development of technology, the increase in social demand and lower installation costs and rapid amortization, have driven a greater use of renewable energy sources in recent years (Rica, 2012). That is why, given the scarce information on the phases of analysis of the calorific value of wood and coal of *Eucalyptus globulus* and *Piptocoma discolor,* species of a commercial nature and with significant heritage in Ecuador will contribute to solving the existing gap on these properties to justify their use in the production of energy in Ecuador.

Materialsand Methods

The wood samples of *Eucalyptus globulus (Eucalyptus)* and *Piptocoma discolor* (Pigüe) were taken in the parish of San Andrés in the province of Chimborazo Canton Guano according to Pan-American standards (COPANT 458) with wooden specimens with a size of approximately 2.5 cm x 2.5 cm in the form of prism of the two species under study while those of charcoal were taken from the property of Mrs. Mélida Coba that is located located in the San Andrés Parish, Guano Canton, Chimborazo Province. The laboratory analyzes were carried out at the Faculty of Natural Resources of the Polytechnic School of Chimborazo.

For the determination of the percentage of the humidity of the wood and the coal of the two species was carried out with the respective procedures according to the international standard ASTM D3173.

After obtaining 5 wooden specimens of 2.5 cm x 2.5 cm and charcoal of each of the species under study, we proceeded as follows: 10 50 ml porcelain crucibles were taken for each study, labeled respectively 5 for each species under study and weighed on the analytical balance, its weight was recorded, then the crucibles are weighed in the stove at 105ºC for 24 hours, at the end the crucibles are weighed and recorded.

The wood samples were taken and weighed in the analytical balance to obtain the initial weight of each of them, the wood samples are introduced respectively in each crucible of each species and their label to enter the stove at 105 degrees Celsius for a period of 24 hours, after that period of time the stove is turned off and the crucibles and samples are removed with tweezers and left For a period of time of 30 min in the desiccator, the crucible + the sample was weighed, this process was repeated until a constant weight of the specimens was obtained.

To calculate the percentage of humidity, the international ASTM D3173 standards were taken into account, in which the following formula is applied:

$$\%H = \frac{(A - B)}{A} * 100$$

Where: A= Initial weight, g of sample used B=Final weight, g of samples after heating In this way, the total of the samples was obtained, a percentage of moisture by weight, related to the wet sample.

To determine the density of the wood of the species under study, it was carried out with the respective procedures according to the COPANT 459 standard.

The samples of each species under study were obtained, the data collection was carried out, a digital calibrator was used in which data of length, width and thickness were taken to obtain the volume, the following formula was applied:

$V = l * a * e$

Where:

l= wide

a= width

e= thickness

The following formula is used to calculate the density:

$$D = \frac{m}{v}$$

Where:

m = period

v = volume

Once all the mass and volume data were obtained, the densities of the wood were obtained both green and dry baked for the species under study.

To determine the density of the charcoal of the species under study, the test tube technique was carried out with the respective procedures according to the Ecuadorian Technical Standard INEN 1986: 2013. Once the coal samples of each species under study were obtained, the test tube technique and data collection were carried out, a 100ml graduated specimen was used, 50 ml of water was added to the specimen and then the coal sample was submerged and the data of the volume of water + coal is taken. Once all the results and data of the density of the coal were obtained, the following formula was applied:

$V = bxaxe$

For thecalculus of the density the same equation is used as the one usedfor wood.

In order to calculate the calorific value of the wood and the carbon of *Eucalyptus globulus* and *Piptocoma discolor*, the volatile material, ash content and fixed carbon of the wood samples had to be obtained until calcination.

To determine the Volatile Material of both wood and charcoal se performed the procedure according to ASTM standard (Standard D3175-89 (02)) and the requirements set by the laboratory. 10 porcelain crucibles of 50 ml were taken for each study, they were labeled respectively 5 for each species in study and proceeded to weigh in the analytical balance, the weight of the crucibles is recorded before and after tarar at 105 ° C in the stove, the samples are weighed with their respective crucible and in which data of each net weight is taken. The muffle was calibrated at a temperature of 900 ° C gradually according to ASTM regulations for volatile material, once the temperature was reached, the samples were entered into the muffle for a set time of 9 minutes, the samples were removed from the muffle with tweezers and gloves and the samples were allowed to

cool in the desiccator for a period of 30 minutes in order to avoid damaging the samples, Equipment and materials because it is at a very high temperature.
Theformula used was as follows:

$$\%MV = \left(\frac{(C-D)}{C}\right) - \%Humedad$$

Where:
C= Initial weight g, of sample used
D= Final weight g, sample after heating
In this way the result of all the samples for the volatile material was obtained.
To determine the ash content of the samples, the procedures of the ASTM standard (Standard D3172-89(02)) and the requirements established by the laboratory were used. 10 50 ml porcelain crucibles were taken for each study, labeled respectively 5 for each species under study and weighed on the analytical scale, the weight of the crucibles is recorded before and after taring at 105 ° C in the stove, the samples are weighed with their respective crucible and in which data is taken from each net weight. The crucibles are introduced to the muffle with a temperature of 450°C to 500°C for one hour. Subsequently, the muffle is programmed at a temperature of 700 ° C to 750 ° C for a period of 2 hours, once the time is reached the muffle is programmed again at a final temperature of 950 ° C for a period of 2 hours until obtaining a complete incineration as indicated by ASTM Standard (D3172-89 (02)). After this period of time, the crucibles are removed from the muffle with a clamp and the crucibles are allowed to cool in the desiccator for 30 minutes and the weights are recorded.
The formula applied was as follows:

$$\%C = \frac{(A-B)}{C} * 100$$

Where:
A= Capsule weight and residues
B= Empty capsule weight
C= Weight of the sample used
To determine the fixed carbon of the wood and coal samples, the procedures of the ASTM standard (Standard D3172-89(02)) and the requirements established by the laboratory were used. The formula applied was as follows:
CF=100-(%MOISTURE+% VOLATIL MATERIAL+% Ash)
In order to calculate the calorific value of the species under study from the wood is done obtaining the results of moisture content, volatile materials, ash and fixed carbon, to obtain this result was calculated according to the formula of GOUTAL (Carbajal, 2012) which is the following:
PC=82c+AV kcal/kg
Where:
C= Percentage of fixed carbon
V= Percentage of volatile material
A= It is the coefficient obtained from the following relationship:

$$A = \frac{V}{(V+C)}$$

Statistical analysis

The fulfillment of the theoretical assumptions of the data of all the determined variables was first analyzed, the tests usedwere the Levene test for homoscedasticity and the Shapiro-Wilk test for normality. Comparison tests are performed for two independent samples using the t-Student Test for the variables that met the assumptions and in the case of the dry density variable that did not meet the two conditions, the Mann Whitney test was applied. All analyses were performed at a 95% confidence level, using the IBM-SPSS 25.0 2.3.1 statistical package.

Results and discussion

Table 1 details the mass, volume and value obtained for the density of the green wood of *Eucalyptus globulus* and *Piptocoma discolor*.

Table 1. Green density of wood

	PERIOD (g)	**VOLUME cm³**	**DENSITY g/cm³**
Eucalyptus globulus	16,76	17,47	0,97
Piptocoma discolor	15,09	17,86	0,84

According to the t-Student test, the green density of *Eucalyptus globulus* wood presented a higher value of 0.97 g/cm³ compared *to Piptocoma discolor* with 0.84 g/cm³ (Table 2), there is a significant difference ($p<0.05$) $p=0.000$; being the difference between both of 0.13 g/cm³. Similar to the value obtained by Espina (2006) in his study basic density of *Eucalyptus globulus* wood in which a density of 0.800 g/cm³ is reported and in the same way similar to what Morejón *et al*. obtains, (2017) in their study physical and mechanical properties of three forest species including *Piptocoma discolor* with a density of 0.70 g/cm³.

In relation to the dry density (Table 2) of the wood, the highest density was obtained by *Eucalyptus globulus*.

Table 2. Dry density of wood

	PERIOD (g)	VOLUME cm³	DENSITY g/cm³
Eucalyptus globulus	10,15	1,89	0,83
Piptocoma discolor	8,14	15,6	0,58

The Mann-Whitney U statistic was 0.000 and the p value (bilateral asyntotic sig.) is 0.009, so the null hypothesis is rejected and the alternating hypothesis is accepted, it is concluded that the density variable of the wood in green of each species differs between them, with a significance level of 5%.

The results of the humidity of the two species under study showed that the species with the highest moisture content was *Piptocoma discolor* with a value of 40.91% followed by *Eucalyptus globulus* with a value of 38.58%. As can be seen the Mann-Whitney U statistician was 0.000 and the value of p (bilateral asyntotic sig.) is 0.009, so the null hypothesis is rejected and the alternating hypothesis is accepted, it is concluded that the humidity variable of the wood of each species differs between them, with a significance level of 5%.

The calorific value from the wood of the 5 wooden specimens of the two species under study, it was found that *Eucalyptus globulus* has greater efficiency with a value of 1065.2 kcal / kg in the calorific value and a value of 840.49 kcal / kg for the species of *Piptocoma discolor*. There was a significant difference ($p<0.05$) $p=0.002$; being the difference between both of 259.52 kcal/kg. Similar to the value obtained by Aguas (2016) in his study the evaluation of the caloric capacity from residues of three species including *Eucalyptus globulus* in which he obtains a calorific value of 2173.903 kcal / kg and in the same way similar to what Villa Pozo (2019) obtains in his study called determination of the technical and economic feasibility of the combustion of *Piptocoma discolor* It obtained a calorific value of 955,280 kcal/kg. The results obtained from the humidity of the coal of the 5 wooden specimens of each species under study resulting in the species of *Piptocoma discolor* having higher moisture content in the coal with 58.2% compared to the lowest value of *Eucalyptus globulus* with 7.34%.

The t-Student test the humidity of *Eucalyptus globulus* charcoal presented a value of 11.43 % compared to *Piptocoma discolor* with 59.37 %, where a significant difference was found ($p<0.05$) $p = 0.000$; being the difference between both of 47.94% of coal moisture. Similar to the value obtained by González Giménez (1990) in his study called characteristics of the coal of 2 species of Eucalyptus among them, *Eucalyptus globulus* in which it obtains a density of 13,530% and in the same way similar to what I report (Cruz, 2019) in his study energy characterization of charcoal in Mexico among the species is *Piptocoma discolor* a density of 50.1%. The results obtained from the density of the carbon of the 5 samples of each species resulting in the species of *Eucalyptus globulus* having a higher density in its carbon (0.36 g / cm^3) in relation to the carbon sample of *Piptocoma discolor* (0.32 g / cm^3).

The Mann-Whitney U statistic was 4.000 and the p value (bilateral asyntotic sig.) is 0.075, so the null hypothesis is accepted and the alternating hypothesis is rejected, it is concluded that the carbon density variable of each species differs between them, with a significance level of 5%.

The results obtained from the calorific value from coal having the species of *Eucalyptus globulus* with a high efficiency in the calorific value of its coal (6885.87 kcal / kg) and for the species of Piptocoma discolor (2517.6 kcal / kg).

According to the t-Student test, the calorific value of Eucalyptus globulus wood presented a higher value of 6719.78 kcal / kg compared to *Piptocoma discolor* with 2604.01 kcal / kg, there is a significant difference ($p<0.05$) $p = 0.000$; being the difference between both of 4115.77 kcal / kg. Similar to the value obtained by Giménez (1990) in his study called characteristics of the coal of Eucalyptus species including Eucalyptus *globulus* in which it obtains a calorific value 7 200.01 kcal / kg and in the same way similar to what Torre (2019) reports in his study calorific value of wood and charcoal of forest species in Peru of obtaining 2793.6 kcal / kg. The t-Student test determined a highly significant difference in the calorific value of the species under study.

CONCLUSIONS

The values of the calorific value from wood for Eucalyptus globulus is 1064.13 kcal/kg and for Piptocoma discolor is 804.61 kcal/kg, and as for the calorific value from coal for *Piptocoma discolor* is 2604.01 kcal/kg and for *Eucalyptus globulus* is 6719.79 kcal/kg, taking into account that the highest efficiency of calorific value of coal practically doubles the value that of the wood in the two species under study.

The moisture content of the wood for Piptocoma discolor is 43.88% and for the species of *Eucalyptus globulus* is 38.77%, determining that the species of Piptocoma discolor with the highest moisture content unlike the other species under study.

The moisture content of coal for Piptocoma discolor is 59.38% and for the *species of Eucalyptus globulus* is 11.43%, determining that the species of Piptocoma discolor with the highest moisture content unlike the other species under study with a very low value of moisture content in coal.

The average densities of the 5 samples of green wood of Piptocoma discolor were 0.85 g / cm^3 and for the species of *Eucalyptus globulus* 0.96 g / cm3 I feel this species with greater density in wood in green. The average densities of the 5 dry wood samples of *Piptocoma discolor* were 0.56 g/cm3 and for the *Eucalyptus globulus* species 0.82 $g/^{cm3}$ being this species with the highest density in dry wood.

The average densities of the 5 samples of *charcoal of Piptocoma discolor* were 0.32 g / cm 3 and for the species of *Eucalyptus globulus* 0.36 g / cm^3 being this species with greater density in dry wood

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