Chemical Composition and Calorific Power of tree species in the Peruvian Andes

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Abstract. Many forest species of the Peruvian Andes are considered exceptional for having innumerable powers, such is the case of the calorific power product of the chemical composition of the species. This study was carried out in the Department of Huancavelica, Izcuchaca District, the analysis of samples was carried out at the National University of Central Peru and the National University of Agraria la Molina, where ASTM Standards were used to obtain data. The species that presented the highest calorific value was Caesalpinia spinosa with 4658.25 kcal / kg, since within its chemical composition it presented a greater amount of extractables and lignin, while the Vachellia macracantha and Tecoma stans species obtained 4422.05 and 4077.1 kcal / kg respectively. However, the three species studied prove to have an excellent calorific value due they are above 4000 kcal / kg.

1. Introduction
The shortage of firewood and charcoal turns out to be a serious problem in the rural communities of Peru, since their availability and the use of this resource are becoming increasingly unattainable due to the little interest in reforestation and the poor management of forest species [1]. Petroleum products turn out to have a high cost, which is why the inhabitants opt for other energy products, such as coal and firewood [2]. From the seven million people who live in the Peruvian highlands, it is estimated that four million use biomass for cooking. Preliminary investigations carried out in Junín and Ayacucho report an average consumption of 1.1 m³ of firewood / person / year [3].

The factors that influence the choice of a fuel are: availability, price, tradition, calorific value and personal preferences. Consequently, these factors must be considered when evaluating fuel consumption [4]. Forest species with excellent energy characteristics are always the most required, many of these species are ideal to be used as firewood, however, their aptitudes are not limited only to being used in that way [5].

For this reason, the study of the chemical components of wood and the calorific value of our forest species is so important to know the characteristics in each tree species and take advantage of them in a sustainable way.
2. Method

2.1. Study place
This research was developed in the province of Izcuchaca at Huancavelica region in Perú, located at 12°30’03”S y 74°59’38”O at 2939 m.a.s.l. in southern Perú in the central Andes, with an undulating relief, with medium-textured soils.

2.2. Sampling method
Two trees of the same species were chosen and marked, to later determine the total height and diameter breast height “DBH”. The logs were selected according to Peruvian Technical Standard “NTP 251.008 - Selection and collection of materials”. Afterwards, the trees of: Caesalpinia spinosa, Tecoma stans and Vachellia macracantha were felled, at a height of 1.30 m. above ground level (basal height), the logs were 1.0 m long each log was covered by an instant adhesion plastic.

The extracted logs were exposed to the environment to be able to dry them and then obtain sawdust that was sieved through a No. 40 sieve (sections 0.42 mm. By 0.42 mm.) And finally this sawdust was deposited in plastic bags duly sealed and coded by species and tree number.

2.3. Laboratory analysis
In the table 1, we show the Standards applied in the research. They were carried out in the Laboratory of Wood Technology and Forest Industries of the Faculty of Forestry and Environmental Sciences of the National University of the Central Peru and in the Biochemistry Laboratory of the Institute of Nutritional Research, of the National University Agraria la Molina.

The chemical composition of the wood in this case of the three forest species already mentioned and obtain the percentages of extractables, lignin, cellulose and ashes, it was carried out using the ASTM methodologies and the Acetic Peroxide method.

This study applied the following Standards:

| Standards | Procedure | Formula |
|-----------|-----------|---------|
| Standard ASTM – D – 1110, 1956 “Solubility of wood in water” | 5 grams of sawdust of known humidity was prepared, to be placed in the thermostat at 105 ° C for 24 hours, this was considered as the dry weight, this was covered with 200ml of distilled water and placed in a water bath equipment for 6 hours. The sawdust was filtered and returned to the thermostat at 105 ° C for 24 hours. | \( Extractive \text{ hot water} \% = \frac{P_1 - P_2}{P_1} \times 100 \) |
| Where: P1: Dry sawdust weight (g) P2: Weight of dry sawdust without extractives (g) |

| Standards | Procedure | Formula |
|-----------|-----------|---------|
| Standard ASTM – D – 1107, 1956 and ASTM – D – 1105, 1956 “Solubility of wood in benzene alcohol” and “Preparation of extractables free wood” | 4 grams of sawdust resulting from the previous procedure were prepared, this was introduced into a thermostat at 105 ° C for 24 hours, this is the weight of the dry sawdust, the sample was placed in the Soxhelt extractor, in the balloon of this extractor the put 150 ml of benzene alcohol, the extraction process took 6 to 8 hours, then the extraction was carried out only with alcohol at 95 ° and washed with distilled water in a water bath equipment at 95 ° C, then The sample was placed in the thermostat and the | \( Extractive \text{ in alcohol benzene} \% = \frac{E.S}{P_1 \times P_2} \times 100 \) |
| Where: E.S: Weight of dry extractives. (Difference of the weight of the ball with extractives with the weight of the ball) (g) P1: Anhydrous sample weight (g) P2: Weight of dry sawdust without extractives (g) |
| Section | Details |
|---------|---------|
| Sample | Sample was weighed as well as the extractor balloon after it had been dried. |
| Cellulose Determination (Method: Peroxide - Acetic) | 1 gram of free extractable sawdust was prepared, 15 ml of hydrogen peroxide and acetic acid (2: 1) were added, the sample was placed in the thermostat at 105 °C for 48 hours, it was removed, filtered and washed with distilled water. The sample was dried and weighed. %Cellulose = \( \frac{C}{M} \times 100 \) Where C: Filtered cellulose weight (g) M: Sample weight (g) |
| Standard ASTM - D - 1106, 1956 "Lignin from wood" | 1 g was weighed. of extractables-free sawdust, 15 ml was added. of 72% sulfuric acid, left to stand for two hours with constant stirring at a temperature of 18 to 20 °C, 560 ml were added. of distilled water, and boiled for 4 hours, filtered and dried in an oven for 2 hours at a temperature of 100 to 105 °C. It was weighed, then the lignin was separated from the filter paper to transform into ash and thus make the correction. Lignin % = \( \frac{\text{Lignin weight} - \text{Ash weight}}{\text{Sawdust sample weight}} \times 100 \) |
| Standard ASTM -D - 1102, 1956 "Ashes in wood" | 1.00 g was prepared. of sawdust, it was introduced to the thermostat at 105 °C for 24 hours, this is the weight of the dry sawdust, the sample was placed in the flask for 3 hours, the equipment was at a temperature that ranged between 575 °C to 600 °C, then it was placed in the glass desiccator for 30 minutes and weighed. %Ashes = \( \frac{C}{Ps} \times 100 \) Where: C: Ash Weight (g) Ps: Dry sawdust weight (g) |
| Determination of the estimated calorific value | It was determined taking into consideration the values obtained from: extractives, lignin, cellulose, ashes, all expressed in percentages. |
| Determination of the experimental higher calorific value | It weighed 0.2 g. of sample in a plastic bag, the bag was tied to the combustion wire of the calorimetric bomb, the support capsules were placed, the pump was closed, as well as the valve located at the top. It was filled with oxygen up to 30 atmospheres, in parallel a bucket was filled with 2000 ml of distilled water. Kcal = \( \frac{(AT° \times ST) - (e1 + e2 + e3)}{\text{Sample weight (ST)}} \) Where AT°: Final temperature - initial temperature e1: Post titration calories e2: Calories released from the wire e3: Calories from the plastic bag ST: It is the average of several Benzoic acids. |

PCSE = 5266 – 16.36CT + 0.23L. CT – 5.73Ce. Ea + 1.76EAB. L Where: PCSE: Estimated higher calorific value (kcal/Kg) Ce: Ash content (%) CT: Total carbohydrate content (%) Ea: Extractives content in hot water (%) EAB: Extractives content in alcohol-benzene (%) L: Lignin content (%)
this should be at 25 °C, the calorimetric bomb was submerged inside the bucket and 2 ignition plugs were placed on the head of the oxygen pump, wait 4 to 5 minutes for the temperature of the pump to equilibrate with that of the bucket. The initial temperature of the bucket was recorded and by pressing the temperature of the bucket for 5 seconds the temperature of the bucket began to increase and after 10 the temperature was recorded, the pump was removed from the bucket, the valve was opened to release the oxygen and I washed the inside of the pump with distilled water, the remains of combustion wires that did not burn were removed and the length of the wire that burned was measured by difference, the measurement of the wire that did not burn was found.

Determination of the lower calorific value

\[ \text{PCI} = \text{PSC} - \text{CV} \]

Where

- PCI: Lower calorific value (kcal / Kg)
- PCS: Higher calorific power (kcal / Kg)
- CV: Heat of vaporization (539 kcal / Kg constant)

3. Results

3.1. Chemical wood composition

Table 2. Summary of averages found by species.

| Species     | Removable in water c. (%) | Extractable in alcohol b. (%) | Cellulose (%) | Lignin (%) | Ash (%) |
|-------------|---------------------------|-----------------------------|---------------|------------|---------|
| *C. spinosa*| 6.75                      | 12.33                       | 46.2          | 30.17      | 0.63    |
| *V. macracantha* | 6.82                    | 9.21                        | 50            | 28.95      | 1.79    |
| *T. stans*  | 5.43                      | 2.53                        | 46.5          | 20.20      | 2.24    |

In Table 2. The extractable percentages for *C. spinosa* and *V. macracantha* are much higher in relation to *T. stans*, especially in the data obtained with the alcohol-benzene method. However, the percentages of cellulose and lignin do not show a significant difference in the three species and finally the ash percentage was higher in *T. stans*. The extractables and lignin are directly proportional to the calorific power, it means that when the quantity of these components increase, the amount of calorific power will increase too. On the other hand in the case of ashes the relationship is indirectly proportional.

Table 3. Averages of calorific power in Caesalpinia spinosa, Vachellia macracantha and Tecoma stans.

| Species - samples | Calorific power (kcal / Kg) | Average (kcal / Kg) |
|-------------------|----------------------------|---------------------|
| *C. spinosa* - C1 | 4608                       | 4658.25             |
| *C. spinosa* - C2 | 4708.5                     |                     |
| *V. macracantha* - V1 | 4452.2                   | 4422.05             |
| *V. macracantha* - V2 | 4391.9                   |                     |
| *T. stans* - T1  | 4103                       | 4077.1              |
| *T. stans* - T2  | 4051.2                     |                     |
In Table 3. The results show us data on the experimental calorific power (calorimetric bomb), where C. spinosa is the species with the highest calorific power followed by V. macracantha and T. stans. The three forest species are above 4000 kcal / kg. Which indicates an excellent calorific power.

Table 4. Average of three types of calorific value in Caesalpinia spinosa, Vachellia macracantha and Tecoma stans.

| Species         | Experimental higher calorific power (kcal / kg) | Estimated calorific power (kcal / kg) | Lower calorific power with pump (kcal / kg) | Estimated lower calorific power (kcal / kg) |
|-----------------|-----------------------------------------------|--------------------------------------|---------------------------------------------|---------------------------------------------|
| C. spinosa      | 4658.25                                       | 5414.22                              | 4119.25                                     | 4875.22                                     |
| V. macracantha  | 4422.05                                       | 5133.38                              | 3883.05                                     | 4594.38                                     |
| T. stans        | 4077.1                                        | 4440.85                              | 3538.10                                     | 3901.85                                     |

The Table 4 shows the comparison between the experimental and estimated calorific power. The difference that exists between these two factors, in the three species is significant, where C. spinosa has the highest calorific value and T. stans the lowest. The experimental calorific power is the most reliable since it adapts to the ASTM standard.

3.2. Microscopic Description of Wood Anatomy

The figure 1 is described in the following order: (1) Distinctive growth rings; diffuse porosity, with a vertical or radially arranged pore arrangement, solitary grouping. (2) vessels with single perforation stage, alternating intervacular puncture; presence of organic extractables like gums and inorganic like rhomboid crystals; pore diameter 89.05 µm on average, major diameter 123.3 µm and minor diameter 94.5 µm, 6 pores P / mm², this means a high density; Vasicentric paratracheal axial parenchyma in some confluent case. (3) Rays with a predominance of 4 to 6 cells and scarce 1 to 3 cells wide and 28 cells long on average and with a maximum and minimum of 43 and 8 cells respectively, long rays, homogeneous procumbent, 3 rays p / mml.

Figure 1. The transversal (1), tangential (2) and radial sections (3) of Vachellia macracantha.

Figure 2. The transversal (1), tangential (2) and radial sections (3) of Tecoma stans.
The figure 2 is described in the following order: (1) Distinctive growth rings; Diffuse porosity with diagonal arrangement, predominantly solitary grouping (2) vessels with simple perforation plate, alternating intervascular round pit; mean pore diameter 78.09 µm, larger pore diameter 123.3 µm and minimum pore diameter 27.4 µm; 21 pores P / mm², this means high wood density; presence of inorganic extractables such as rhomboid crystals; Diffuse paratracheal axial parenchyma. (3) Rays with a width of 1 to 3 cells with a predominance of three “triseriate” cells with an average length of 10 cells and with a maximum and minimum of 15 and 5 cells respectively, procumbent homogeneous rays, 5 p / mml rays.

Figure 3. The transversal (1), tangencial (2) and radial sections (3) of Caesalpinia spinose.

The figure 3 is described in the following order: (1) Distinctive growth rings; Diffuse porosity with diagonal arrangement, predominantly solitary grouping. (2) Vessels with a simple perforation stage, intervascular puncture with an alternating predominance and little ladder; presence of gums; mean pore diameter 98.61 µm, major diameter 164.4 µm and minor diameter 54.8 µm, 9 pores p / mm², this means a very high wood density; Vasicentric axial paratracheal parenchyma. (3) Rays with width of 1 to 3 cells, predominance of two “biseriate” cells and height of 16 cells on average and with maximum and minimum of 7 and 19 cells respectively, procumbent homogeneous, 6 radii p / mml.

4. Discussion
According to Table 4, the experimental calorific power in C. spinosa, V. macracantha and T. stans was 4658.25, 4422.05 and 4077.10 kcal / kg respectively. The estimated calorific value in C. spinosa, V. macracantha and T. stans was 5414.22, 5133.38 and 4440.85 kcal / kg respectively, the variation of the experimental and estimated calorific power is because there are different standards for the extraction of cellulose, lignin, extractables and ashes, in addition to the variability of chemical components in the same tree [6]. The high calorific value in the species is due to the presence of high percentages of extractables and lignin. One of the factors that influences the decrease in the calorific value is the percentage of humidity due to its need for heat energy for the evaporation of water and consequently decreases the amount of calorific value [7], another factor that influences the decrease of the calorific value is the percentage of ashes such as calcium, potassium, silica, magnesium, phosphorus and sulfur that are slowly oxidizing [8]. In a study Acacia macracantha presented 3817.75 kcal / kg of calorific value, unlike the data presented in the present study, this variation is due to the percentage of extractables, the species studied, the level of the tree studied, time of year, age and place [5,9]. Haplorhus peruviana, a species similar to those studied, has a calorific value of 4513.68 kcal / kg, this result is similar to those found in the species presented [1], Acacia dealbata has an average calorific value of 4300 kcal / kg. Acacia mearnsii, 4528 kcal / kg and Tecoma stans (Juss) H.B.K 4127.98k kcal / kg similar values with the species studied [10, 11, 12].

5. Conclusion
In this study, it was possible to identify that of the three species studied, C. spinosa, turns out to be the one with the highest calorific power with 4658.25 kcal / kg. This is due to the fact that extractables and lignin have a higher amount of carbon in their composition and a lower amount of oxygen, in
addition to presenting a lower amount of inorganic compounds (ashes), followed by V. macracantha with 4422.05 kcal / kg. On the other hand, T. stans presented a lower calorific value of 4077.1 kcal / kg, because in its chemical composition it has a lower quantity of extractables and lignin, and a greater quantity of inorganic compounds, which implies a reduction of the calorific value since these they do not burn or they burn at a temperature higher than that used, so this component influences the amount of calorific power of the species.

6. References

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