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# EVALUATION OF THE CHARACTERISTICS OF LEUCAENA STEM (*Leucaena leucocephala*) CHARCOAL FROM ANIMAL FEED WASTE IN WEST SULAWESI

**Zulkahfi*, Daud Irundu, Vanto Niger, Novita Sari Parenden, Nurfadilla**
Universitas Sulawesi Barat
*Email: zulkahfi@unsulbar.ac.id

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**ABSTRACT**

Current energy use still relies on fossil fuels, the use of which can cause pollution and greenhouse gases. One alternative that can replace these materials is biomass. One potential material is leucaena stem, which is processed into charcoal. Therefore, the purpose of this study is to evaluate the characteristics of leucaena stem charcoal using the complete pruning technique in West Sulawesi. This study used appropriate tools and materials to produce leucaena stem charcoal and liquid smoke, observed the microscopic characteristics, tested the moisture and ash content, and tested the calorific value of leucaena stem charcoal. The results showed that there were deposits in the pores, causing the dead stem to be harder and producing fewer cracks in the charcoal product. The yield of charcoal and liquid smoke is inversely proportional, where the highest charcoal yield is in dead stem samples at 36.59% with the lowest liquid smoke yield at 28.57%. In addition, the lowest average moisture content was detected in dead leucaena stem charcoal at 0.2%, while the highest ash content was detected in the same charcoal at 2.9%. The highest calorific value of leucaena stem charcoal was found in the 5-time pruning treatment at 34.50 KJ/g. In general, the chemical properties of leucaena stem charcoal are of high quality and comply with Indonesian national standards.

**Keywords**: Leucaena; Wood; Charcoal; Calorific_Value; Pyrolysis.

## INTRODUCTION

Energy is one of the most important aspects of social life. Currently, energy use still focuses heavily on fossil fuels, which can cause extreme climate change and greenhouse gases (IPCC, 2022). Global warming can be reduced by decreasing the use of fossil-based energy in various sectors (IEA, 2021). Biomass is a potential alternative source of energy that is rapidly renewable, carbon neutral, and cheaper to produce (Ozoliņa et al., 2022). One of the Indonesian government's current programs is to increase energy security, particularly by transitioning from fossil fuels to biomass-based energy. This is evidenced by the increase in biodiesel production every year (Anditya et al., 2025). West Sulawesi, in particular, also requires high amounts of fuel, especially for the production of patchouli oil and palm sugar, which are high in (Kurnia, 2025). The production process for both products has been using firewood sourced from tree exploitation, which poses a risk to the environment (Harmay, 2025). This situation must be addressed immediately with solutions for the development of fast-growing and potential biomass in West Sulawesi, one of which is the leucaena plant.

The leucaena plant (*Leucaena leucocephala*) is a fast-growing plant that can be cultivated in low-nutrient soils with high temperatures and salinity (Bageel & Borthakur, 2022). The potential of the leucaena plant is ideal for development as an energy plantation. Leucaena plants that grow for one year have fresh biomass in the stems of 24.56 tons/ha, branches of 8.63 tons/ha, and leaves of 5.57 tons/ha (Pengpit et al., 2024). Leucaena leaves are rich in protein (Thamaga et al., 2021), making them suitable as feed for goats in West Sulawesi. On the other hand, the stems and branches are still largely unused and left to rot on their own or are only used as firewood on a household scale. Biomass contains high levels of water and other substances that result in low calorific value, making it unsuitable for direct use as fuel. Leucaena plant biomass can be developed into charcoal products as an innovation to increase its calorific value as an energy source.

Charcoal is a product of biomass cooking using pyrolysis techniques to release various contents in biomass and leave carbon content, so that charcoal can produce higher calorific value compared to dry biomass. Several studies have detected that wood charcoal can produce high calorific value (de Meira et al., 2021; Otieno et al., 2022). The use of leucaena leaves as animal feed has been widely practiced, especially in West Sulawesi. Leucaena leaves are pruned at various intervals, marked by leucaena plants with dense foliage where the leaves are removed using a complete pruning system. Extensive leaf pruning can produce high wood density (Leng et al., 2025). In addition, leucaena stem microscopically has fiber characteristics with a high holocellulose content of >68% (Sivan et al., 2023). This condition allows leucaena stem with leaf pruning to produce high-quality charcoal. Several studies have detected a relationship between wood density and charcoal density and energy (Couto et al., 2022; Gomes et al., 2024). Therefore, the purpose of this study was to evaluate the characteristics and the quality of Leucaena stem charcoal from livestock feed waste using the complete pruning technique in West Sulawesi.

## RESEARCH METHODOLOGY

### Time and Location

This research was conducted over a period of five months in 2025, starting with sampling in the village of Bababulo, Pamboang District, Majene Regency, West Sulawesi Province. Charcoal production and quality testing were carried out at the Integrated Laboratory of the University of West Sulawesi.

### Research Materials

This study used leucaena stem as the main material, obtained from a leucaena plantation owned by a goat farmer in Bababulo village, West Sulawesi. The wood came from leucaena plants that had undergone leaf pruning treatments with variations of non-pruning, 1 time pruning, 3 times pruning, 5 times pruning, and wood from dead plants. Other materials used to test the calorific value included 0.1 N NaOH solution, 1% phenolphthalein solution, distilled water, and 0.1 mm nickel wire.

### Research Equipment

This study used various tools such as pyrolysis technology equipment for the production of charcoal and liquid smoke from leucaena stem (Figure 1), a stereo microscope for observing the microscopic characteristics of wood and charcoal, *an* XRY-A1 *Oxygen Bomb Calorimeter* to test the calorific value, a torch to test the ash content, and a drying oven to test the moisture content of the samples.

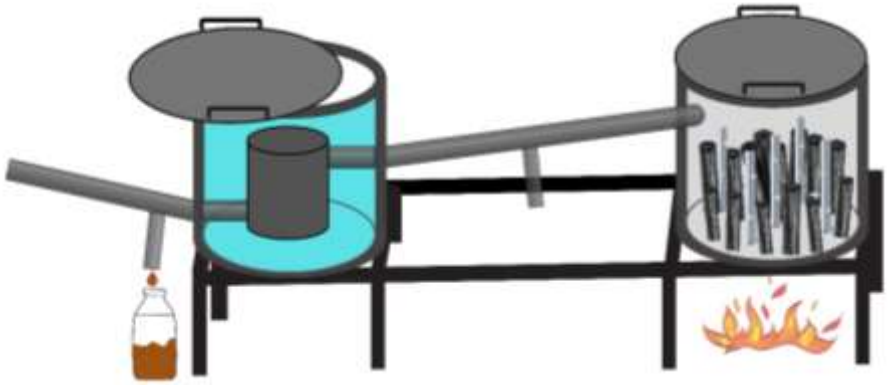


Figure 1. Pyrolysis device design

**Preparation and production of charcoal and liquid smoke from leucaena stem**

The leucaena stem obtained was dried for 8 days and then separated from the bark. The wood was then weighed to obtain the weight of the wood sample ($W_1$). The wood was then placed in a pyrolysis device that was heated for 3 hours at a temperature of 200-400$^o$ C. During the heating process, the condensation section is kept cool to produce liquid smoke. After that, the heating is stopped and the pyrolysis device is cooled for ±5 hours until it returns to room temperature. The charcoal and liquid smoke samples produced are then weighed to obtain the weights of the charcoal ($W_c$) and liquid smoke ($W_{ls}$). This procedure produces charcoal and liquid smoke products with a production amount determined based on gravimetric calculations using equation (1), where Ch% is the percentage of charcoal yield, LS% is the percentage of liquid smoke yield, and Non-Condensable Gases (NCG).

$$Ch\% = \frac{W_c}{W_1} \times 100,\ LS\% = \frac{W_{ls}}{W_1} \times 100, \text{ and } NCG\% = 100\% - (Ch\% + LS\%) \quad (1)$$

**Microscopic observation of leucaena stem and charcoal samples**

Microscopic observation of leucaena stem samples was conducted using a stereo microscope to examine the microstructure of leucaena stem. Charcoal samples produced from the pyrolysis combustion process were also examined for their microstructure. The results of these two observations produced images of the microstructure of leucaena stem and charcoal to compare the structure of the wood before and after it became charcoal.

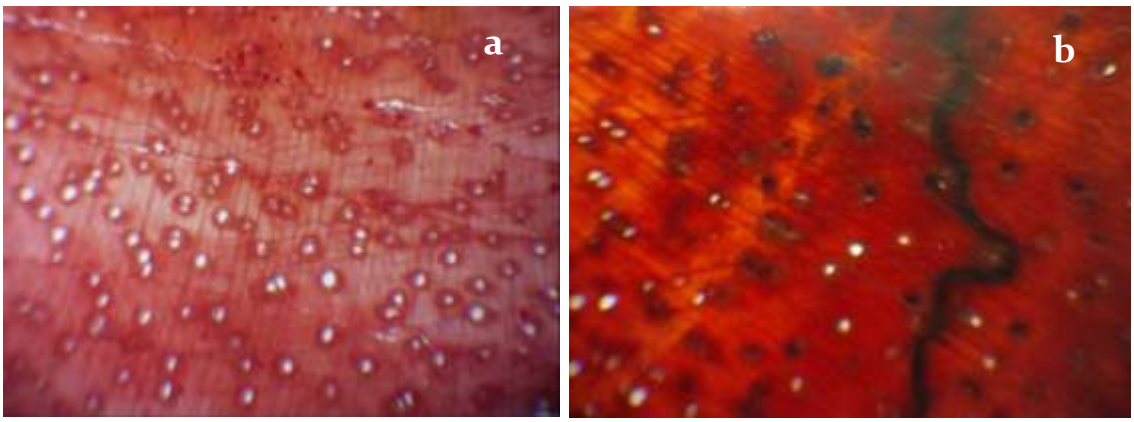



Figure 2. Macroscopic characteristics of leucaena stem (a) living stem, (b) dead stem

**Measurement of the moisture content of leucaena stem charcoal**

A sample of 2 g ($B_1$) of charcoal powder was placed in a heat-resistant container and put in a drying oven for 6 hours at a temperature of 105±3° C. The oven-dried sample was then placed in a desiccator to balance the sample temperature, then weighed to obtain the weight of the sample after oven drying ($B_2$). The moisture content of leucaena stem charcoal can be determined based on gravimetric calculations using equation (2), where MC% is the percentage of moisture content.

$$MC\% = \frac{(B_1 - B_2)}{B_1} \times 100 \quad (2)$$

**Measurement of ash content of leucaena stem charcoal**

A sample of 1 g ($M_1$) of charcoal powder was placed in a porcelain crucible and heated to a temperature of over 650° C for 3 hours until the ash weight was constant. The ash sample was placed in a desiccator to balance the sample temperature. The sample was then weighed to obtain the ash weight ($M_2$). The ash content of leucaena stem charcoal can be determined based on gravimetric calculations using equation (3), where AC% is the ash content percentage.

$$AC\% = \frac{M_2}{M_1} \times 100 \quad (3)$$

**Measurement of temperature increase and calorific value of leucaena stem charcoal**

Measurement of temperature increase and heat value of leucaena stem charcoal using *an* XRY-A1 *Oxygen Bomb Calorimeter* with a 1% phenolphthalein solution and 0.1 N NaOH solution. A sample of 0.7-1.0 g (M) of leucaena stem charcoal was placed in a chamber container and inserted into a bomb tube with a 10 cm long nickel wire and 10 ml of distilled water. The inner bucket was filled with 1.5 L of water and the outer bucket with 6 L. The temperature was gradually increased 18 times over 540 seconds. The length of the unburned nickel wire was measured again, while the charcoal combustion residue in the bomb tube was washed with distilled water and then 3 drops of 1% phenolphthalein solution were added. The solution was then titrated with 0.1 N NaOH solution until the solution changed color, and the amount of NaOH solution used was recorded. The calorific value of leucaena stem charcoal was calculated based on Indonesian National Standard (SNI) 01-6235-2000 using equation (4), where Hg(cal/g) is the calories per gram of sample, t is the temperature increase, w is 2426 calories/° C, $l_1$ is ml of NaOH used for titration, $l_2$ is 13.7 x 1.02 x sample weight, $l_3$ is 2.3 x the length of the nickel wire burned, and M is the sample weight (g).

$$Hg(cal/g) = \frac{tw - l_1 - l_2 - l_3}{M} \quad (4)$$

**Data Analysis**

The study employed an experimental design using a completely randomized design. The independent variable was the pruning level (non-pruning, 1 time pruning, 3 times pruning, 5 times pruning, and deadwood), with each treatment repeated three times. Analysis of the effect of pruning levels on the moisture content, ash content, and calorific value of leucaena stem charcoal was conducted using analysis of variance (ANOVA) at a 95–99% confidence level. Post-hoc tests were conducted using Duncan's test with the same replicates. Subsequently, a Pearson correlation analysis was performed between moisture content, ash content, and the calorific value of leucaena stem charcoal using the Statistical Package for the Social Sciences (SPSS) version 25.

## RESULT AND DISCUSSION

### Yield of Leucaena stem Pyrolysis Process

The quality of leucaena stem charcoal can be seen in Figure 3. The results show that the charcoal yield tends to be the same for each leucaena stem with and without pruning, at around 24.21-27.90%. Previous studies utilizing variations in charcoal burning temperature produced similar leucaena charcoal yields (Singh et al., 2022). However, samples of dead leucaena stem produced the highest yield, reaching 36.59%. This is thought to be because dead stem forms hard, thick fibers, which result in high yields when burned. Xylem or wood cell thickening occurs during the process of killing birch trees. In addition, killing trees can reduce the number of pores and thicken cell walls (Serkova et al., 2022).

One of the products resulting from the pyrolysis process is liquid smoke, which is produced through the condensation of smoke in gaseous form into a liquid substance. The results show that the amount of charcoal is inversely proportional to the amount of liquid smoke obtained. The results show that the highest amount of liquid smoke was obtained from leucaena stem samples with 5 pruning at 38.04% with the lowest charcoal yield at 24.21%. Conversely, dead stem samples produced the lowest amount of liquid smoke at 28.57% with the highest charcoal yield at 36.59%. This is in line with the research by (de Meira et al., 2021), who found that the amount of charcoal was inversely proportional to the amount of liquid smoke from various types of wood. Liquid smoke mostly comes from the lignocellulose structure and a small portion contains inorganic compounds (Batista & Gomes, 2021; Oyebode & Ogunsuyi, 2021). Liquid smoke products have their own potential for use as insecticides (Hagner et al., 2020), and food preservatives with antibacterial properties (Wang et al., 2021). In addition, there are other products in the form of non-condensable gases and tar.

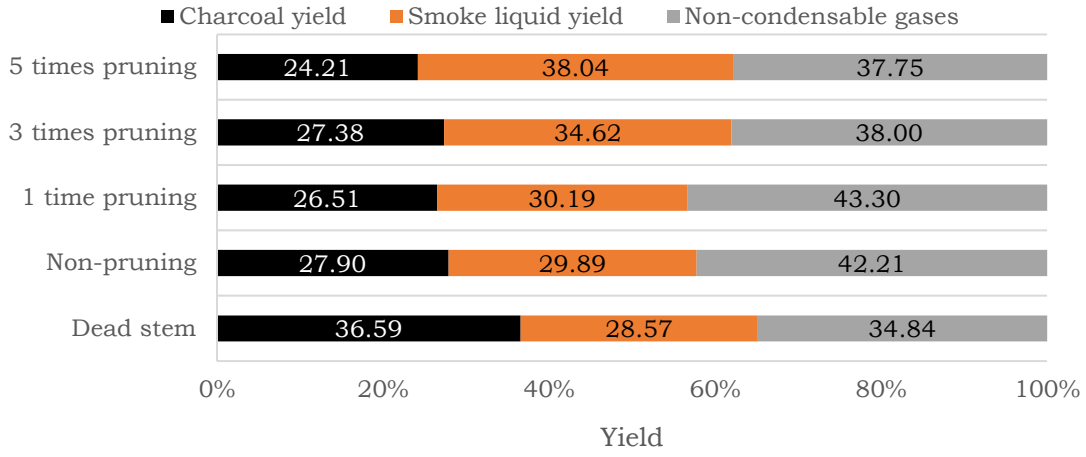
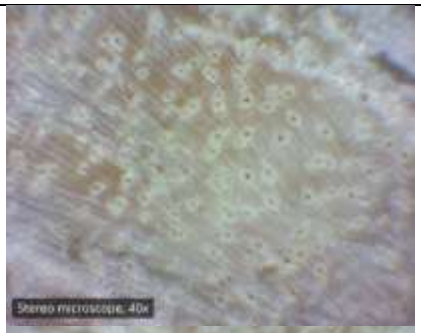
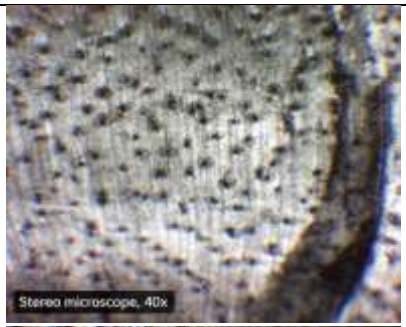
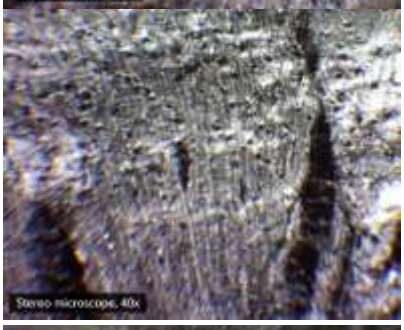



Figure 3. Gravimetric yield of pyrolysis processes of leucaena stem

### Characteristics of Leucaena stem Charcoal Samples

The microscopic characteristics of leucaena stem in the axial section have pores that are randomly arranged with multiple pore distribution. These characteristics are shown in leucaena stem with leaf pruning and wood without leaf pruning, as well as in dead stem (Figure 2). Leaf pruning treatment has an impact on leucaena stem yield, where wood samples with leaf pruning produce wood with denser fibers. In addition, dead trunks show drier wood and high fiber density (Table 1).

Table 1. Characteristics of leucaena stem and charcoal

| Variables | Leucaena stem | Leucaena stem Charcol |
|---|---|---|
| Non-Pruning |  |  |
| 1 time Pruning |  |  |
| 3 times Pruning |  |  |
| 5 times Pruning |  |  |
| Dead Steam |  |  |

The results show that leucaena stem samples vary after being turned into charcoal depending on the treatment. Charcoal made from living wood shows cracks in the axial section when turned into charcoal. These cracks are thought to originate from the wood cell walls, which suddenly lose moisture and extracts, damaging the wood fiber structure when burned at high temperatures. Wood cell walls can be damaged

by water in the cell wall structure when exposed to high temperatures (Shi et al., 2018). Table 1 shows that there are physical differences in the charcoal produced from wood with various treatments, with wood from dead trunks producing charcoal with fewer cracks. This is thought to be because dead stem contains low water content due to the wood pores being filled with wood extract. This is in line with the microscopic observations in Figure 2, which show that the pores in dead stem are closed and blackened. This is consistent with the research by (Vititnev & Kazitsin, 2025), who found that wood fibers are darker in dead wood than in living wood.

**Quality of Leucaena stem Charcoal**

The determination of leucaena stem charcoal quality based on moisture content, ash content, and calorific value can be seen in Table 2. Leucaena stem charcoal shows varying moisture content values among treatments in leucaena plant samples, ranging from 0.2% to 1.2%. This moisture content is still in accordance with the Indonesian National Standard of a maximum of 8% (BSN, 2000). Similar studies show higher moisture content in leucaena charcoal (Pengpit et al., 2024). The lowest moisture content was found in charcoal from dead leucaena stem, at 0.2%. This is thought to be because the stems of dead trees experience a cessation of plant physiological processes, such as water absorption from the soil, resulting in low water content in the plant stems. Pruning or killing trees can stop xylem formation, thereby reducing and stopping water transport to the leaves (Salomón et al., 2024).

Table 2. Quality of leucaena charcoal energy products.

| Variable | Quality of Charcoal | | |
|---|---|---|---|
| | Water content (%) | Ash (%) | Calorific value (KJ/g) |
| Dead steam | 0.20 (0.05)a | 2.90 (0.17)a | 32.03 (5.48)a,b |
| Non-Pruning | 1.20 (0.33)b | 2.10 (0.20)b | 29.75 (1.43)a,b |
| 1 time pruning | 0.63 (0.10)c | 2.06 (0.32)b | 27.64 (7.06)a,b |
| 3 times pruning | 1.13 (0.15)c | 1.96 (0.21)b | 25.51 (0.28)b |
| 5 times pruning | 0.52 (0.13)a,b | 2.06 (0.15)b | 34.50 (3.99)a |
| Average | 0.74** | 2.22** | 29.88$^{ns}$ |

Note : ** = high significant ($P$<0,01); ** = significant ($P$<0,05); ns = not significant

Another important component related to the quality of charcoal as an energy source is its ash content. Energy is influenced by the amount of carbon, volatile matter, and ash content in charcoal, which are important components in determining the energy in charcoal. Based on Table 2, the ash content tends to be low in leucaena stem charcoal from various pruning treatments, with an average of 1.96%-2.90%. This amount is low and still within the Indonesian National Standard with a maximum ash content of 8% (BSN, 2000). Several other studies show higher ash content in the charcoal produced (Pengpit et al., 2024; Setkit et al., 2021; Singh et al., 2022). The ash content produced is even lower than the ash content of coal (Singh et al., 2022). This is because leucaena stems initially have a low ash content (Lin et al., 2024; Pengpit et al., 2024). Based on the leaf pruning treatment given, the ash content was higher in charcoal from leucaena plants without pruning. This is because without pruning, leucaena plants can grow tall. The ash content increases with the increase in plant height.

Solid and liquid energy products can release heat that can be measured by a calorimeter bomb to produce a number of caloric values that characterize the quality of an energy source. Based on Table 2, the average caloric value produced by leucaena stem charcoal is around 29.88 KJ/g, which is still in accordance with the Indonesian National Standard with a minimum standard of 20.93 KJ/g (BSN, 2000). This

indicates that the charcoal from all five treatments has a high calorific value and meets the national requirements for charcoal. It is suggested that Leucaena stems generally contain large amounts of C, H, and O, which contribute to their high calorific value. The C, H, and O components are often used as parameters for determining High Heating Value (HHV) (Abdulyekeen et al., 2024; Pengpit et al., 2024; Setkit et al., 2021). Charcoal does not yet have a high energy value and has a low initial heat increase. The increase in charcoal temperature produced is still relatively low (Figure 4) even though it complies with SNI 01-6235-2000. The results show an initial temperature increase in leucaena stem charcoal of around 1-2° C and can only reach a temperature of 2-3° C for 540 seconds, when compared to the initial temperature increase in other energy source materials which reaches 2.5° C and can reach a temperature of up to 5.5° C for 540 seconds.

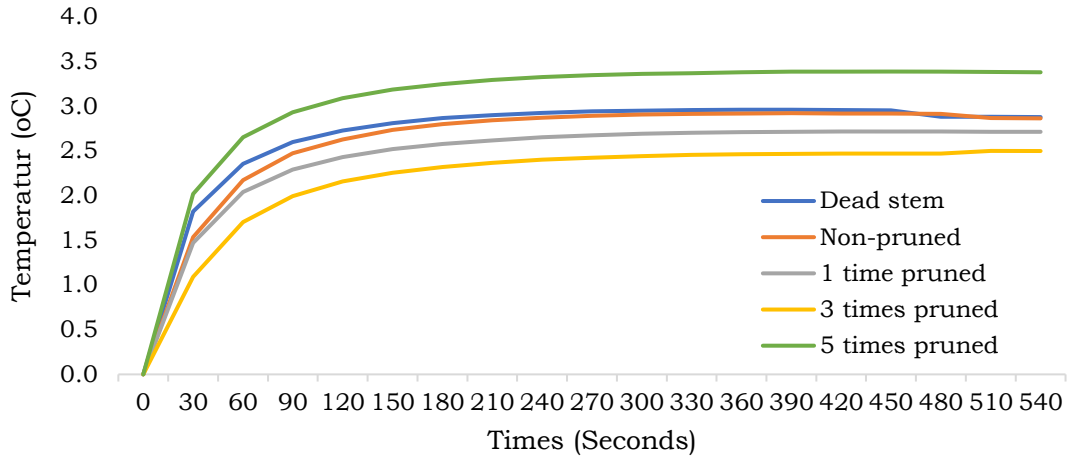



Figure 4. Increase in combustion temperature of leucaena stem charcoal

Table 3. Pearson correlation analysis between moisture content, ash content, and calorific value of leucaena charcoal

| Parameters | r-value | p-value | Description |
|---|---|---|---|
| Moisture content x Ash content | -0.577 | 0.024* | Moderate correlation (0.41-0.60) |
| Moisture content x Calorific value | -0,440 | 0.101$^{nt}$ | Moderate correlation (0.41-0.60) |
| Ash content x Calorific value | -0,026 | 0.926$^{nt}$ | Very low correlation (0.01-0.20) |

Note : ** = high significant ($P$<0,01); * = significant ($P$<0,05); ns = not significant

The results of the Pearson correlation analysis (Table 3) indicate a significant moderate correlation between moisture content and ash content, such that as moisture content increases, ash content decreases. This is likely because the mineral components in the ash possess hydrophobic properties, enabling them to repel water from the charcoal. There is no significant relationship between ash content and calorific value, this indicates that the level of ash content in charcoal does not affect its calorific value. On the other hand, the results of the correlation analysis between moisture content and calorific value showed no significant (p-value) relationship but indicated a moderate relationship (r-value), such that the higher the moisture content, the lower the calorific value produced. This is thought to be because moisture content can reduce the temperature during the charcoal combustion process, resulting in a low calorific value. This is consistent with research showing that a decrease in moisture content in briquettes can produce a high calorific value (Akowuah et al., 2012; Inegbedion, 2022).

## CONCLUSIONS

The research was conducted in several stages, starting from observing the characteristics of the wood, producing charcoal and liquid smoke, and testing the quality of leucaena stem charcoal. The results showed that there were deposits in the pores, causing the dead stem to be harder and producing fewer cracks in the charcoal product. The yield of charcoal and liquid smoke was inversely proportional, with the highest charcoal yield in dead stem samples at 36.59% and the lowest liquid smoke yield at 28.57%. Conversely, the 5-time pruning treatment resulted in low charcoal yield (24.21%) and the highest liquid smoke yield (38.04%). In addition, the lowest average moisture content was detected in dead leucaena stem charcoal at 0.2%, while the highest ash content was detected in the same charcoal at 2.9%. The highest calorific value of leucaena stem charcoal was found in the 5-time pruning treatment at 34.50 KJ/g, which exceeded the calorific value in the Indonesian National Standard.

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## REFERENCES

Abdulyekeen, K. A., Daud, W. M. A. W., & Patah, M. F. A. (2024). Torrefaction of wood and garden wastes from municipal solid waste to enhanced solid fuel using helical screw rotation-induced fluidised bed reactor: Effect of particle size, helical screw speed and temperature. *Energy*, *293*. https://doi.org/10.1016/j.energy.2024.130759

Akowuah, J. O., Kemausuor, F., & Mitchual, S. J. (2012). *Physico-Chemical Characteristics and Market Potential of Sawdust Charcoal Briquette*.

Anditya, C., Prananto, A. B., Suroyo, H., Halim, L., & Anggreani, D. (2025). *Handbook of Energy& Economic Statistics of Indonesia 2024*. Ministry of Energy and Mineral Resources Republic of Indonesia.

Bageel, A. M., & Borthakur, D. (2022). The effects of pH, salinity, age of leaves, post-harvest storage duration, and psyllid infestation on nutritional qualities of giant leucaena fodder. *Journal of Crop Science and Biotechnology*, *25*(4), 381–392. https://doi.org/10.1007/s12892-021-00139-9

Batista, R. R., & Gomes, M. M. (2021). Effects of Chemical Composition and Pyrolysis Process Variables on Biochar Yields: Correlation and Principal Component Analysis. *Floresta e Ambiente*, *28*(3), 1–12. https://doi.org/10.1590/2179-8087-FLORAM-2021-0007

BSN. (2000). *Standar Nasional Indonesia Briket arang kayu*.

Couto, A. M., Monteiro, T. C., Trugilho, P. F., Lima, J. T., da Silva, J. R. M., Napoli, A., & de Almeida, D. P. (2022). Influence of physical-anatomical wood variables on charcoal physical–mechanical properties. *Journal of Forestry Research*, *34*(2), 531–538. https://doi.org/10.1007/s11676-022-01462-9

de Meira, A. M., Nolasco, A. M., Klingenberg, D., de Souza, E. C., & Dias Júnior, A. F. (2021). Insights into the reuse of urban forestry wood waste for charcoal production. In *Clean Technologies and Environmental Policy* .23(10), 2777–2787). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s10098-021-02181-1

Gomes, G. S. L., Neto, S. N. de O., Carneiro, A. de C. O., Lopes, L. S. de S., Leite, H. G., & Caldeira, M. V. W. (2024). Influence of spacing between trees on wood and charcoal quality indicators. *Cerne*, *30*(1). https://doi.org/10.1590/01047760202430013270

Hagner, M., Tiilikkala, K., Lindqvist, I., Niemelä, K., Wikberg, H., Källi, A., & Rasa, K. (2020). Performance of Liquids from Slow Pyrolysis and Hydrothermal Carbonization in Plant Protection. *Waste and Biomass Valorization*, *11*(3), 1005–1016. https://doi.org/10.1007/s12649-018-00545-1

Harmay, M. (2025, February 1). *"Simalakama" Nilam*. Https://Wacana.Info/Berita/7045/%20wacana.Info.

IEA. (2021, May 18). *Net Zero by 2050*. Https://Www.Iea.Org/Reports/Net-Zero-by-2050.

Inegbedion, F. (2022). *MANAS Journal of Engineering Estimation of the moisture content, volatile matter, ash content, fixed carbon and calorific values of saw dust briquettes*. *10*(1), 17–20. https://doi.org/10.51354/mjen

IPCC. (2022). *AR6 Synthesis Report, Climate Change 2022*. Https://Www.Ipcc.Ch/Report/Sixth-Assessment-Report-Cycle/.

Kurnia, Y. (2025). *Provinsi Sulawesi Barat Dalam Angka 2025* (M. Mansur, Ed.; Vol. 21). BPS Provinsi Sulawesi Barat.

Leng, W., Cao, P., Chen, C., & Tang, L. (2025). The Influence of Pruning on the Growth and Wood Properties of Populus deltoides "Nanlin 3804." *Forests*, *16*(5). https://doi.org/10.3390/f16050848

Lin, P. H., Ko, C. H., Tu, S. H., & Lin, C. J. (2024). Leucaena leucocephala and Montmorillonite Co-pyrolysis Biochar: A Study on Physicochemical Properties and Stability. *BioResources*, *19*(2), 3857–3872. https://doi.org/10.15376/biores.19.2.3857-3872

Otieno, A. O., Home, P. G., Raude, J. M., Murunga, S. I., & Gachanja, A. (2022). Heating and emission characteristics from combustion of charcoal and co-combustion of charcoal with faecal char-sawdust char briquettes in a ceramic cook stove. *Heliyon*, *8*(8). https://doi.org/10.1016/j.heliyon.2022.e10272

Oyebode, W. A., & Ogunsuyi, H. O. (2021). Impact of torrefaction process temperature on the energy content and chemical composition of stool tree (Alstonia congenisis Engl) woody biomass. *Current Research in Green and Sustainable Chemistry*, *4*. https://doi.org/10.1016/j.crgsc.2021.100115

Ozoliņa, S. A., Pakere, I., Jaunzems, D., Blumberga, A., Grāvelsiņš, A., Dubrovskis, D., & Daģis, S. (2022). Can energy sector reach carbon neutrality with biomass limitations? *Energy*, *249*. https://doi.org/10.1016/j.energy.2022.123797

Pengpit, P., Chotchutima, S., Chaiprapat, S., Yoyrurob, S., & Charnnok, B. (2024). Enhancing bioenergy and feed production in Southern Thailand: An approach through Leucaena cultivation and hydrothermal carbonization. *Renewable Energy*, *237*. https://doi.org/10.1016/j.renene.2024.121673

Salomón, R. L., Miranda, J. C., Rubio-Cuadrado, Á., Sobrino-Plata, J., Rodríguez-Calcerrada, J., López, R., Gil, L., & Valbuena-Carabaña, M. (2024). Testing root trenching and stem girdling as silvicultural treatments in abandoned oak coppices. *Forest Ecology and Management*, *555*. https://doi.org/10.1016/j.foreco.2024.121722

Serkova, A. A., Tarelkina, T. V., Galibina, N. A., Nikerova, K. M., Moshchenskaya, Y. L., Sofronova, I. N., Nikolaeva, N. N., Ivanova, D. S., Semenova, L. I., & Novitskaya,

L. L. (2022). Changes in the Differentiation Program of Birch Cambial Derivatives following Trunk Girdling. *Forests*, *13*(8). https://doi.org/10.3390/f13081171

Setkit, N., Li, X., Yao, H., & Worasuwannarak, N. (2021). Torrefaction behavior of hot-pressed pellets prepared from leucaena stem. *Bioresource Technology*, *321*. https://doi.org/10.1016/j.biortech.2020.124502

Shi, J., Lu, Y., Zhang, Y., Cai, L., & Shi, S. Q. (2018). Effect of thermal treatment with water, H2SO4 and NaOH aqueous solution on color, cell wall and chemical structure of poplar wood. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-36086-9

Singh, A. K., Singh, R., & Sinha, O. P. (2022). Characterization of charcoals produced from Acacia, Albizia and Leucaena for application in ironmaking. *Fuel*, *320*. https://doi.org/10.1016/j.fuel.2022.123991

Sivan, P., Rao, K. S., & Rajput, K. S. (2023). Chemical Composition in Juvenile and Mature Wood of Branch and Main Trunk of Leucaena leucocephala (Lam.) de Wit. *Plants*, *12*(23). https://doi.org/10.3390/plants12233977

Thamaga, M. W., Mokoboki, H. K., Sebola, N. A., & Ravhuhali, K. E. (2021). Apparent digestibility and nutritional composition of Leucaena leucocephala (Lam) leaf meal incorporated in the diets of Black Australorp and Potchefstroom Koekoek chicken breeds. *Tropical Animal Health and Production*, *53*(5). https://doi.org/10.1007/s11250-021-02922-w

Vititnev, A., & Kazitsin, S. (2025). Using Siberian Fir (Abies sibirica) Dead wood in Wood Fiberboard Production. *BioResources* , *20*(3), 5315–5330. https://doi.org/10.15376/biores.20.3.5315-5330

Wang, J., Potoroko, I., & Tsirulnichenko, L. (2021). Wood vinegar and chitosan compound preservative affects on fish balls stability. *Food Bioscience*, *42*. https://doi.org/10.1016/j.fbio.2021.101102