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PRELIMINARY STUDY ON PROPERTIES OF SMALL DIAMETER WILD LEUCAENA LEUCOCEPHALA SPECIES AS POTENTIAL BIOMASS ENERGY SOURCES

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ABSTRACT

The heavy reliance on non-renewable energy sources from fossil fuel such as petroleum, natural gas and coal has led to the scarcity of these sources and occurrence of global warming. This phenomenon raises the public concerns to diversify the energy sources to sustain energy availability. To address these predicaments, biomass is among the prominent alternative energy sources since it is renewable and possesses minimal harms to the environment. Leucaena leucocephala, or locally known as 'Petai Belalang' is one of the potential energy crops. In this study, 3 portions of Leucaena leucocephala stem which are bottom, middle and top have been divided and 2 different particle sizes which are 0.5 and 1.5 mm were used to determine their influences on the properties of the samples. Proximate analysis (moisture content, volatile matter, ash content and fixed carbon), physical analysis (specific gravity and bulk density) plus calorific value of Leucaena leucocephala were conducted as the parameters to determine the properties of the samples. Among the proximate parameters, portions differ significantly ($p < 0.01$) in moisture content, volatile mater and ash content except for fixed carbon. Whereas, particle sizes shown significant differences ($p < 0.01$) in moisture content, ash content and fixed carbon while differing ($p < 0.05$) in volatile matters. Both independent factors differ significantly ($p < 0.01$) in the physical parameters, including specific gravity and bulk density. The highest calorific value was observed in the bottom portion with particle size 0.5 mm which is 18.56 MJ/kg, whereas calorific values are significantly differing ($p < 0.01$) for both independent factors. In conclusion, Leucaena leucocephala species show a good result to be as potential biomass energy sources.

Keywords: leucaena leucocephala species, renewable energy, biomass energy, proximate analysis, physical analysis, calorific value.

1. INTRODUCTION

The worldwide energy in recent times has evoked global concerns regarding the rapid depleting fossil fuel resources. According to the New Policies Scenario of International Energy Agency (IEA), the world energy demand is forecasted to be continually increased every year by about 1.2% from 2008 to 2035 with 70% of the growth in demand coming from developing countries [29]. This increase will be largely (87%) met by energy derived from finite, non-renewable fuel sources. Developing countries will be responsible for the majority of the future growth in energy demand and greenhouse gas (GHG) emissions due to their unprecedented levels of economic growth [13].

This has alerted public that heavy reliance on non-renewable energy resources should be alleviated while diversification of energy resources should be promoted to sustain the energy availability. In Malaysia, the overall energy demand has triply increased from the year 1990 to 2009 [31] due to the faster economic growing as well as industrial development. Moreover, the installation of power plants is accelerating and the power plant capacity is increased from 14,291 to 24,377 MW between year 2000 to 2009 [26]. Hence, it is notoriously known that the availability of non-renewable energy resources mainly natural gas and coal in Malaysia is exhausted rapidly. To address this predicament, the diversification of energy resources is predominantly essential to remedy the situation. As a result, the government has resorted to identify available and preferably renewable energy resources to ensure the sustainability of energy resources and energy security.

Among the variety of renewable energy resources, biomass is one of the prominent choices to be used as the raw material to generate electricity [16, 2]. Biomass is presently estimated to contribute 10-14% of the world's energy supply [23]. The modernization of biomass encompasses technology improvements including combustion, gasification and pyrolysis to increase the efficiency of biomass energy production. In modern applications, the biomass energy is generally being widely used for household applications such as improved cooking stoves and use of biogas as well as small cottage or large industrial applications for electricity generation [9]. However, the potential of biomass energy is difficult to extrapolate, especially on a global scale. The ease of estimating resource availability, economics of production and use as well as ecological, socioeconomic development and environmental considerations have to be taken into account when accessing the implications.

Biomass energy in Malaysia possesses potential due to the availability of the varied agricultural, forestry and livestock residues in the country. The development of biomass energy in the current state is focusing on the development of fuel supply and conversion routes that minimize environmental impacts. The suitable energy crops for biomass generally produce high yield with low energy input and growing fast with short rotation. Oil palm has been currently the most productive source of biomass, which is more than 85% in Malaysia [12]. However, the overdependence on the sole source of biomass energy can result in unsustainability environmental issues. The practice of monoculture can lead to several problems such as low soil fertility, wide spread of pest and inefficiency in resource use. Hence, diversification of biomass energy is critical to provide a sustainable source of alternative energy and increase the ecosystem resilience.

Malaysia is one of the richest countries in biodiversity and it possesses a high potential for biomass crop diversification. A number of underutilized biomass species are yet to be discovered which can be planted to provide a sustainable source of energy. Leucaena leucocephala which is being considered as one of the potential forest plantation plants by the Malaysian Timber Industrial Board (MTIB). Leucaena leucocephala which locally known as 'Petai Belalang' has astonished thousands of people for its high density wood yields, fast growth and its strong adaptability. Leucaena leucocephala fulfills the economic aspects by supplying potential input for biomass energy resources as well as providing more fertile soils and aids in preventing soil erosion in environmental perspective. In recent research, Leucaena leucocephala is indicated to have the potential for thermal conversion and could be used as substrates for ethanol production [30].

The study of Leucaena leucocephala now focuses on its potential properties to be used as one of the prominent biomass energy resources due to small diameter stem (DBH 5-8 cm). Biomass source, particularly Leucaena leucocephala in this case is believed to act as an alternative source of energy as well as vital role in the welfare of the global environment. There is no net-up build of CO_2 considering the CO_2 released in combustion is compensated for by that absorbed by the growing energy crops [9]. Assuming that the amount of biomass grown is equivalent to that burnt, the sustainability of biomass can be accomplished in terms of diversification of energy sources and global warming mitigation perspective.

2. MATERIALS AND METHODS

Materials

The materials which were investigated in this study is Leucaena leucocephala, or locally known as 'Petai Belalang'. The small diameter of wild Leucaena leucocephala species about the same height (around 1.9 m) were obtained randomly from local residential areas in Kuala Terengganu, Terengganu, Malaysia. The species samples were collected based on their diameter sizes (5-8 cm) in decay-free and optimum growth condition. The stem was then cut into 3 different portions (bottom, middle and top) and dividing into 2 different particle sizes, particularly 0.5 and 1.5 mm.

Methods

Several procedures were carried out to prepare the Leucaena leucocephala for further analysis on its properties. The raw material which is Leucaena leucocephala stem were sampled then followed by cutting the stem into 3 different portions, particularly bottom, middle and top. To analyze the properties of Leucaena leucocephala species, a series process of chipping, crushing, drying and grinding by mean of machinery process were carried out to transform the stems into sawdust form. The screening process was continued on mesh sizes and 2 different particle sizes will be divided, particularly 0.5 and 1.5 mm. Every 2 different particle sizes sample from 3 different portions were then tested to analyze the properties for its raw form.

Analysis of leucaena leucocephala

Several testing were carried out to study the properties of Leucaena leucocephala based on proximate, physical analysis and energy content. The proximate analysis consists of moisture content, volatile matter, ash content and fixed carbon. The physical analysis was carried out for the testing of bulk density and specific gravity. The energy content was referred to as the measurement of calorific value in different sizes according to their different portions.

Proximate analysis

The proximate analysis was carried out for the purpose to study the thermal properties of Leucaena leucocephala particularly based on its moisture content (%), volatile matter (%), ash content (%) and fixed carbon (%). All procedures and analysis were performed according to the American Society of Testing and Materials (ASTM).

Moisture content

One of the major factors in the biomass energy content is moisture content, which is preferably ranging between 8-12 %. According to [5], the mold formation and degradation may occur. Lower moisture content is usually preferable since more heat per unit mass can be produced. The test procedures of moisture content were carried out according to the guidelines of ASTM D3173. The moisture analyzer MX-50 machine was used in the identification of moisture content in the samples based on the formula as shown by Eqn. (1).

$$\text{Moisture Content (\%)} = \frac{M_g - M_0}{M_0} \times 100\% \quad (1)$$

Where M_g = green weight of wood (g) and M_0 = Oven-dry weight of wood (g).

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Volatile matter

To test the volatile matter of the samples, the test procedures ASTM D3175 were followed. Specific amount of sawdust samples, which is more than 1 g be placed inside a small crucible enclosed with cap. The weight of samples was then measured by analytical balance. The samples were then burned in a furnace for 7 minutes at a temperature of 900ºC. The volatile matter of the sample was generally calculated by Equation (2).

$$\frac{\text{Initial mass(g)} - \text{Mass of residues (g)}}{\text{Initial Mass (g)}} \times 100 \qquad (2)$$

Ash content

The test procedures ASTM D3174 were followed to test the ash content of samples. The mass of the sample is weighed before the testing of ash content in a small crucible without a cap. The selected amount of samples will be burned in a furnace for 3 hours under temperature of 815ºC. Generally, high ash content is less preferable since the formation of ash layer will lead to incomplete combustion. The ash content of the sample was generally calculated by Equation (3).

$$\text{Ash (\%)} = \frac{A \times 100}{B} \qquad (3)$$

where A = weight of ash (g) and B = weight of test sample (moisture free) (g).

Fixed carbon

The fixed carbon value was calculated through the obtained results of moisture content, ash content and volatile matter. It was obtained through the summation of percentage in all 3 different values of moisture content, ash content and volatile matter subtracted from 100%. The fixed carbon of the sample was generally calculated by Equation (4).

$$\text{Fixed Carbon(\%)} = 100(\%) - MC(\%) + VM(\%) + AC(\%) \qquad (4)$$

where MC = moisture content, VM = volatile matter and AC = ash content.

Physical analysis

Physical properties of Leucaena leucocephala, particularly bulk density and specific gravity were studied.

Bulk density

Bulk density is a very important characteristic of substances such as powders, granules and other particles like solid substances. Bulk density if defined as the mass of a bulk material divided by the volume occupied by that material. Bulk density of wood particles was estimated by using beakers and the weights of the samples will be determined by using an analytical balance. Later, the densities of the samples were calculated by using Equation (5).

$$\rho = \frac{m}{v} \qquad (5)$$

Where ρ = density, m = mass and v = volume .

Specific gravity

Specific gravity of wood can be varied due to several factors, including the geographic location of trees and moisture content, which varies by species, diameter at breast height (DBH), age and stem position. The electronic MD300s was used to determine the selected sawdust chips and calculated by using Equation (6).

$$SG = \frac{W_{Asample}}{W_{AH_2O}} \qquad (6)$$

Where SG = specific gravity, $W_{Asample}$ = weight of sample and W_{AH2O} = weight of water.

Energy content

The calorific value particularly is important properties of heating value to be determined. The test procedure was followed ASTM D2015 which is a standard test method for gross calorific value of the sample through Adiabatic Bomb Calorimeter. The automatic Calorimeter 500 that has been used for this testing need to be connected with computer software for one hour initially before testing. The combustion chamber was determined to be in dry condition and the oxygen gas valve was opened. The sample was weighed and then put into the holder crucible. The ignition wire was then coiled in U-shaped and tied to the both end connectors above the crucible. The oxygen gas was then supplied in the container after the cap vessel was tightened. The calorific value of the sample was then obtained after 3-7 minutes of equilibrating and analyzing.

3. RESULTS AND DISCUSSION

Proximate analysis

In proximate analysis, the test procedures of ASTM D3172-07a: Standard Practice for Proximate Analysis of Coal and Coke were used in the characterization of Leucaena leucocephala according to their different portions and particle sizes. To predict the behavior of the sample as a fuel, proximate analysis is one of the most important characterization methods. Proximate analysis refers to the moisture content, ash content, volatile matter and fixed carbon which expressed in weight percent in dry basic (wt. % in dry basis). These proximate analyses were tested according to 3 different portions (bottom, middle and top) and 2 particle sizes (0.5 and 1.5 mm) respectively to determine their influences on these parameters.

Three replications were carried out for each testing and the mean of proximate analysis parameters were obtained respectively. Table-1 shows the mean of these parameters which encompasses moisture content, volatile matter, ash content and fixed carbon of the tested samples in 3 different portions and 2 particle sizes.

Table-1. Mean value of proximate analysis of Leucaena leucocephala.

Portions	Particle Size (mm)	Mean Value			
		Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)
Bottom	0.5	7.13	84.16	2.20	6.51
	1.5	5.44	84.72	0.52	9.31
Middle	0.5	7.94	82.52	2.22	7.32
	1.5	6.18	83.92	0.65	9.25
Top	0.5	8.23	81.46	2.57	7.73
	1.5	6.34	82.67	0.69	10.31

Moisture content

The proximate analysis readings obtained were compared to the EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use to ensure cost-efficient production of high quality fuel according to the requirements of the boiler producers. The highest moisture content of the samples was observed in the top portion with 0.5 mm particle size which is 8.23%. Comparing the middle and bottom portion with same particle size which is 7.94% and 7.13% respectively, where it shows slightly higher values in the top portion. In contrast, the lowest moisture content was observed in the size particle of 1.5 mm in the bottom portion, which is 5.44%, followed by 6.18% in the middle portion and 6.34% in the top portion.

The trend in the result indicates that moisture content is observed to be higher in the finer particles for each different portion. According to [37], the ability of small particle size to absorb water is better than large particle size. In an environment with stable temperature and relative humidity, wood samples are like other hygroscopic materials which eventually reach a moisture content that yields no vapor pressure difference between the wood and the surrounding air. In other words, its moisture content will stabilize at a point called the equilibrium moisture content (EMC). In this case, the stored amount of water in the coarser particle size mixtures was loss faster during the processing of the wood samples. Thus, the moisture content of that mixture was lower. Besides, the moisture content was observed in a trend of increasing from bottom to top portion.

Although the moisture content of these six types of wood samples are acceptable under the European Standardization Organization, higher moisture content contributes non valuable weight to the fuel. Moisture decreases the effective bulk density of woods as well as its useful energy content and the quality and efficiency of combustion. According to [10], high moisture content in fuels lengthens the drying residence times and thus it requires larger chambers. Besides, moisture increases the microbial respiration which in turn affecting the physical quality of the wood samples particularly its durability. In fact, the amount of carbon monoxide (CO) released during the combustion process of the woods is lesser in low moisture content [8].

Volatile matter

Volatile matter refers to the wood fraction (except moisture) released when it burns at high temperature in the absence of air (so that it does not burn). It is made of organic or inorganic parts of the biomass, which encompasses the combustible (gaseous C_xH_y, CO or H_2) and non-combustible fraction (CO_2, SO_2, NO_2, H_2O and SO_3). The result of volatile matter of wood samples tested shows the highest 84.72% in the bottom portion with particle size 1.5 mm, while the lowest reading was observed in the top portion with particle size 0.5 mm which is 81.46%. According to [36], biomass fuels generally contain high quantity of volatiles which usually varies between 76 and 86 wt. % dry basic (d.b.) in woody biomass particularly. From the observation, the volatile matter content in the six different wood samples is generally high and above 80% which meet the standard of EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use.

Comparing the volatile matter in 2 different particle sizes, the volatiles in particle sizes of 1.5 mm are slightly higher than particle sizes of 0.5 mm for 3 portions of the samples. Generally, the finer particles consume lesser time to ignite. For fine particles, the moisture evaporates faster and the release of volatile matter begins earlier [8, 27]. On the other hand, the larger particles continue to devolatilize while char of the fine particles is being oxidized and thus the secondary reactions within the pores are reduced [1]. The volatile matter resulted is thus lower in finer particle sizes.

Ash content

According to EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use; the proximate analysis of wood without bark in dry basis is 0.3 % of ash. However, the ash content of wood based biomass is less than 2% and highest in bark ranging 2-5% which collects sand and other impurities. In this proximate analysis, the maximum ash content was observed in the top portion with particle size of 0.5 mm which is 2.57% while the minimum is 0.52% which is observed in the bottom portion with 1.5 mm particle size. The ash content of the samples was observed in an increasing trend from the bottom to top portion. A similar trend was observed by [18], in which top portion of the trees in all selected species were observed with a higher percentage of ash content. This is probably due to the mobilization of higher amount of potassium (K) and magnesium (Mg) at the top portions of trees. The top portion of the plant are highly metabolizing portion, where the nutrients from the soil is fixed before transporting to the other parts of the plant [6, 33]. The ash content is observed to be higher in finer particle sizes. In [4] stated that smaller particle size contains ash content two times more than larger particles. This is due to inorganic matter tends to be concentrated in the smaller sized particles.

The ash content of the six types of samples is accepted as low as content wood and suitable for biomass fuels. In fact, high ash content decreases high heating

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value (HHV) and combustion yields because of losses by poor combustion. It may generate slag deposits, which creating higher thermal resistance to heat transfer and requiring more expensive equipment maintenance [10].

Fixed carbon

Fixed carbon also known as non-combined carbon is the fraction remaining after the volatile matter is completely released with the exception of ash and moisture, which burns forming char [28]. The highest fixed carbon was observed in top portion 1.5 mm with 10.31%, while the lowest fixed carbon was found in bottom portion 0.5 mm with 6.51%. Among the trend of fixed carbon amount in six different types of samples, the relationship between volatile matter and fixed carbon is observed. Samples which are highly volatile have resulted in lower fixed carbon. According to [28], the higher the fixed carbon, the easier the ignition and thus the lower the residence stage until combustion is completed. When biomass materials are heated in a combustion process, the volatile matter releases first and burn in gaseous state. While the fixed carbon is left behind as char, which burns later in solid state.

Physical analysis

The physical characteristic of wood samples which encompasses its bulk density and specific gravity in various portions and particle sizes has been determined. Table-2 shows the mean value of the physical analysis of the wood samples according to their portions and particle sizes.

Table-2. Mean value for physical analysis of Leucaena leucocephala.

Portions	Particle Size (mm)	Mean Value	
		Bulk Density (kg/m^3)	Specific Gravity
Bottom	0.5	294.27	1.36
	1.5	146.57	1.25
Middle	0.5	283.10	1.29
	1.5	145.17	1.17
Top	0.5	259.34	1.23
	1.5	130.43	1.08

Bulk density

Basically, bulk density is calculated on the basis of the measured weight and the bulk volume which expressed in kilograms per cubic meter (kg/m^3). It is affected by many factors, such as the chip dimensions, chip moisture content and size of the sample. Wood bulk density typically varies from about 200 to 1000 kg/m^3. The highest bulk density was observed in the bottom portion of wood samples with particle size 0.5 mm in 294.27 kg/m^3, while the smallest value, 130.34 kg/m^3 was found in the top portion with particle size of 1.5 mm.

According to [3], among the biomass fuels, typical bulk density of wood chips (less than 30% moisture content) is 250 kg/m^3. In this case, the bulk density was observed to be higher in smaller particle sizes for all different portions. This trend resembles the research of [22], particles from larger screen openings will result in lower bulk density. Similar findings are also presented by [11], the mean of wood bulk density observed according to EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial used generally ranging from 150 to 201 kg/m^3 in which the highest reading was observed in smaller particle sizes. Other biomass materials including wheat straw, switch grass and barley straw display a similar trend in which the bulk density decreased as the particle sizes increased [21]. This is probably due to the increment in pore spaces between larger particles, leading to decrease in bulk density.

The bulk density of the wood samples was observed in a decreasing trend from bottom to top portion. According to [34], the wood bulk density is inversely correlated to the tree height which indicates lower bulk density in the upper portion of the tree. According to [20], bulk density plays an important role in transportation and storage capacity. Eventually, low density of biomass materials poses a problem in the handling, transportation, storage and the combustion process.

Specific gravity

Theoretically, specific gravity is a measure of the ratio of the density of wood as compared to the same volume of water. It has no unit since it is a ratio. According to [39], specific gravity refers to oven-dry weight of wood sample divided by the sample volume in green condition which divided by the density of water (1 g/cm^3). Specific gravity and its pattern within a tree are considered as a prominent index of wood strength properties, particularly for wood utilization and in understandings stems mechanics [7, 38]. In previous studies, the specific gravity was observed in several tropical species which varied from the pith to the bark and with different heights of the stem.

In this study, the highest reading for specific gravity is observed in the bottom portion with particle size of 0.5 mm which is 1.36. Whereas, the lowest reading is 1.08 which was observed in the top portion with particle size of 1.5 mm. The specific gravity was observed with a trend which its values decrease from the bottom to top portion which are 1.36, 1.29 and 1.23 respectively for particle size 0.5 mm, while it decreases from 1.25, 1.17 and 1.08 respectively for particle size 1.5 mm. This result resembled the findings by [7] in which specific gravity was found to be higher at the base of the tree than below the living crown. Compared to another tropic species, B. quanta is found to have higher specific gravity at the base compared to the upper portion of the tree [7, 14]. According to [32], the variations of wood specific gravity within different portions of trees is due to the alterations in cell size and cell wall thickness which are associated with annual and periodic growth cycles and the increasing age of the cambium.

There are similar trends of wood specific gravity observed by [19]. The decreasing specific gravity along

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the bottom to top portion is probably due to the higher fiber and the parenchyma wall thickness in bottom portion which led to the increment of total volume of a woody substance as compared to upper portion. According to [24], the average fiber and wall thickness increased from the top height to bottom height of the tree.

Energy content

The energy content which also known as calorific value is the most essential parameter, which reflects effectiveness and efficiency of any fuel by determining the amount of heat generated from a unit mass (MJ/kg). Factor affecting the amount of heat produced by fuel refers to its quantitative conversion of carbon and hydrogen present in the fuel, to water and carbon dioxide and is a function chemical-elemental composition of fuel [18, 35]. According to [2], calorific value is categorized into 2 types which are gross calorific value (GCV) or caloric value on oven-dry weight basis and ash-free calorific value (AFCV). In this case, the calorific values in six different samples were determined on its GCV by using auto calorimeter. Table-3 indicates the average value of calorific value in various portions and particle sizes.

Table-3. Mean value for energy content of leucaena leucocephala.

Portions	Particle Size (mm)	Mean Value Calorific Value (MJ/ kg)
Bottom	0.5	18.56
	1.5	18.97
Middle	0.5	17.35
	1.5	18.36
Top	0.5	16.59
	1.5	17.81

From the result shown in Table-3, the highest calorific value was observed in the bottom portion with particle size of 1.5 mm, which is 18.97 MJ/kg. The lowest calorific value reading was found on top portion 0.5 mm which is 16.59 MJ/kg. According to [3], the typical calorific value of oven-dry wood chips as fuel is around 19 MJ/kg.

In [17] research on determining calorific value, ash content, wood density and elemental composition of 7 commonly used fuel woods which stated that the calorific value ranged between 19.70-23.40 MJ/kg. The variation between these previous findings compared with this research is probably due to the difference in ash content in the wood samples. Calorific value of Leucaena leucocephala was observed in a decreasing trend from the bottom to top portion. The mean calorific value of wood sample from bottom to top portion were 18.56, 17.35 and 16.59 MJ/kg respectively for particle size of 0.5 mm while for 1.5 mm were 18.97, 18.36 and17.81 MJ/kg respectively. This result resembled the finding of [40] in which the calorific value of stem wood is decreasing bottom to the top portion. According to [18], the variation of calorific value of pine wood was investigated in a similar pattern, decreasing with tree diameter and height. In fact, the calorific value of wood is mainly influenced on its major biochemical components including cellulose, hemi-cellulose, lignin, extractives and other ash forming minerals [15].

Analysis of variances (ANOVA) on proximate, physical analysis and energy content of leucaena leucocephala

To compare the proximate, physical analysis and energy content of 3 different portions (bottom, middle and top) and 2 particle sizes (0.5 and 1.5 mm), two-way ANOVA statistical analysis was carried out. Table-4 displays the results of the proximate, physical analysis and energy content obtained by the two-way ANOVA statistical analysis. In this analysis, there are mainly 2 independent variables which are portions and particle sizes of wood samples. The dependent variables are referred as the proximate analysis (moisture content, volatile matter, ash content and fixed carbon), physical analysis (bulk density and specific gravity) and energy content (calorific value).

Table-4. ANOVA on proximate, physical analysis and energy content of leucaena leucocephala.

Source	Dependent Variables	Sum of Squares	Df	Mean Square	F-Ratio
Portion	MC	3.283	2	1.641	20.792**
	VM	16.904	2	8.452	12.154**
	AC	0.229	2	0.114	9.616**
	FC	3.821	2	1.191	3.042 ns
	BD	2123.77	2	1061.88	168.99**
	SG	0.068	2	0.034	35.953**
	CV	7.459	2	3.729	143.74**
Particle size	MC	14.222	1	14.222	180.16**
	VM	5.104	1	5.104	7.210*
	AC	13.227	1	13.227	1.113**
	FC	26.718	1	26.718	42.539**
	BD	85921.7	1	85291.7	1.36E**
	SG	0.075	1	0.075	79.621**
	CV	3.476	1	3.476	133.97**

Note: MC = moisture content; VM = volatile matter; AC = ash content; FC = fixed carbon; BD = bulk density; SG = specific gravity; CV = calorific value; *significant value, $p < 0.05$; **significant value, $p < 0.01$; ns not significant

From the statistical data, the hypothesis was made whether a different portion of the samples have significant effects on the proximate analysis. The portions of the wood samples significantly differed ($p < 0.01$) in moisture content, volatile matter and ash content and moisture content but not significantly ($p > 0.05$) in fixed carbon. This result indicates that wood samples in portions of bottom, middle and top do not affect fixed carbon. Besides, another hypothesis has made in this proximate analysis in which different particle sizes of the wood samples have significant effects on the proximate analysis.

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The particle sizes of the samples significantly differing ($p < 0.01$) in moisture content, ash content and fixed carbon while differing ($p < 0.05$) in volatile matter. This indicates that moisture content, ash content and fixed carbon are significantly influenced by the particle sizes at 99% confidence level. The hypothesis is accepted. In fact, the moisture content of the samples is higher in the finer particles due their larger surface area to absorb moistures from the surroundings.

In two-way ANOVA statistical data, the hypothesis was made that whether different portions within the wood has an effect on its physical analysis, namely bulk density and specific gravity. The portions of the wood sample (bottom, middle and top) differs significantly ($p < 0.01$) in both bulk density and specific gravity. In this case, the hypothesis is accepted. The specific gravity decreased from the bottom to top portion of the samples. Different portions of wood samples significantly affect its bulk density, which it decreases from bottom to top portion. This is probably due to variation of moisture content in different portions due the differences in their composition. Different particle sizes were hypothesized to have significant effects on specific gravity and bulk density of the wood samples. In the statistical data, particle sizes differ significantly ($p < 0.01$) in bulk density and specific gravity. This indicates the variation of specific gravity of the samples was related to its particle sizes. However, the effect of particle sizes on its bulk density was rather obvious, in which it is higher in finer particle sizes. This is probably due to its dependence on the consolidated strength. Coarser particles in this case, 1.5 mm are not as compressible due to the large pore spaces between them and hence the bulk density is lower. Finer particles have larger consolidation strength as they are more compressible, hence their bulk density is observed to be higher.

The hypothesis was made to determine whether the portion and particle sizes of the samples influenced its energy content significantly. From the statistical data, different portions (bottom, middle and top) and particle sizes (0.5 and 1.5 mm) differ significantly ($p < 0.01$) in energy content (calorific value). This indicates the energy content of the samples is significantly varied among different portions and particle sizes. According to [18], the preliminary study of selected wood species shows that the energy content tends to decrease with the height of trees. This resembled the finding in this research in which the highest calorific value was observed in the bottom portion. Particle size of samples was significantly ($p < 0.01$) in energy content (calorific value). Finer particle sizes were observed to have lower calorific value compared to larger particles same reported by [4]. This is probably due to higher amount of tenacious organic material in larger particles. Larger particles contain the cell wall matrices for lignin, cellulose and hemicellulose while small particles comprising soluble organic molecules along with the inorganic molecules.

4. CONCLUSIONS

Proximate analysis

In conclusion, the different particle sizes in the proximate analysis which consists of moisture content, volatile matter, ash content and fixed carbon had shown an obvious influences on wood raw samples. Whereas, the analysis in the various stem portions shows a slightly apparent effect towards those proximate analyses with fixed carbon as an exception. Moisture content, ash content and fixed carbon were observed in a trend of increasing from bottom to top portion while the volatile matter decreases with the height of the wood. Besides, moisture content and ash content were higher in smaller particle sizes (0.5 mm) while in contrast volatile matter and fixed carbon were higher in 1.5 mm particles. According to EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use, 3 important proximate analysis of the samples obtained particularly moisture, ash content and volatile matter passed the standard as determination of its fuel quality and specifications for non-industrial wood chips. The comparison between proximate analysis obtained and qualitative values for non-industrial wood chips according to EN14961-4 is shown in Table-5. Generally, biomass fuel has lower moisture and ash content and higher volatile matter due to their influences on the calorific values.

Table-5. Comparison between proximate analysis of leucaena leucocephala and qualitative values for non-industrial wood chips according to EN14961-4.

Proximate Analysis	Wood Chips						
	Bottom Portion		Middle Portion		Top Portion		Standard EN14961-4
	0.5 mm	1.5 mm	0.5 mm	1.5 mm	0.5 mm	1.5 mm	
MC (%)	7.13	5.44	7.94	6.18	8.23	6.34	< 10 % (Class A1)
VM (%)	84.16	84.72	82.52	83.92	81.46	82.67	> 80 %
AC (%)	2.20	0.52	2.22	0.65	2.57	0.69	< 1.0 % (Class A1) < 3.0 % (Class B2)
FC (%)	6.51	9.31	7.32	9.25	7.73	10.31	-

Note: MC = moisture content; VM = volatile matter; AC = ash content; FC = fixed carbon

Physical analysis

In conclusion, the physical analysis for both of the portions and particle sizes had clearly affected the specific gravity and bulk density in the raw samples tested. Both specific gravity and bulk density show decreasing from bottom to top portion. Smaller particle sizes (0.5 mm) were observed with a higher specific gravity and bulk density in this case. Wood bulk density observed in this research, particularly with particle size of 0.5 mm is acceptable according to EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use as shown in Table-6.

Table-6. Comparison between physical analysis of Leucaena leucocephala and qualitative values for non-industrial wood chips according to EN14961-4.

Physical Analysis	Wood Chips						
	Bottom Portion		Middle Portion		Top Portion		Standard EN14961-4
	0.5 mm	1.5 mm	0.5 mm	1.5 mm	0.5 mm	1.5 mm	
BD (kg/m^3)	294.3	146.6	283.1	145.2	259.3	130.4	150–200 kg/m^3 (Class A1)

Note: BD = bulk density

Energy content

The calorific value of the raw samples tested in various stem portions and different particle sizes shows obvious differences in the energy content analysis. Calorific value shows a decreasing from bottom to top portion while increasing proportionally with the particle sizes of the samples. According to EN14961-4 Solid biofuels; Fuel specifications and classes; Part 4: Wood chips for non-industrial use, all of the samples both for portions and particle sizes show acceptable for calorific value in the circumstances moisture content of the samples equal or below than 10%, with samples from the top portion (0.5 mm) as exception as shown in Table-7. That mean stem from small diameter of Leucaena leucocephala species have the potential to be an alternative for biomass energy sources especially from short rotation woody crops, and it can be enhanced through pelletizing or torrefaction.

Table-7. Comparison between energy content of leucaena leucocephala and qualitative values for non-industrial wood chips according to EN14961-4.

Energy Content	Wood Chips						
	Bottom Portion		Middle Portion		Top Portion		Standard EN14961-4
	0.5 mm	1.5 mm	0.5 mm	1.5 mm	0.5 mm	1.5 mm	
CV (MJ/kg)	18.56	18.97	17.35	18.36	16.59	17.81	MC≤ 10% CV≥17 MJ/kg

Note: CV = calorific value; MC= moisture content

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