The Effect of Different *Khaya Senegalensis* Raw Feedstock Particle Sizes On Solid Fuel Pellet Quality

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**Abstract.** In recent years, the usage and demand for biomass pellet has been increasing due to the need of substitution for non-renewable energy source. Therefore, high quality solid fuel is in need to cater this demand. Pellet qualities such as durability, calorific value and density are different depending on the type of material, size of particle and the density of the feedstock. In this study, the durability, calorific value and unit density of *Khaya Senegalensis* pellet was investigated. This was done to identify the optimum particle size to obtain the best qualities of pellet possible. The ground biomass material was separated into 0.15 mm, 0.50 mm and 1.00 mm particle sizes, pelletized and ultimately the pellet durability, calorific value and unit density were tested in this study. It was found that 0.15 mm particle size resulted in the highest pellet durability, and density value. 1.00 mm particle size pellet has the highest calorific value. As a conclusion, different raw biomass feedstock particle size will affect the durability, density and calorific value of pellet.

1. **Introduction**

Renewable energy resource has been in high demand because of the finite supplies of fossil fuels, rising energy demand and environmental energy concern. Lignocellulosic biomass is a dependable energy source because it does not conflict with the food production rate and available in large amount which can also promote environmental sustainability. Thus, the usage of pellet made from biomass or wood helps in providing alternative product to replace the usage of fossil fuel such as using pellet for combustion rather than using coal. Based on previous research, it can also be concluded that transportation and storage cost can also be reduced due to the physical and mechanical characteristic of the pellet which can save space and increase pellet durability [1]. Several studies have been reported on pelleting, focusing on material, process parameters and bonding formation [2–4]. Some previous research already proved that mechanical properties of wood pellets would change due to exposure to high humidity in stockpiles or severe environmental condition changes [5,6].

In this research, the effect of biomass moisture content and the different particle size towards the highly durable pellet as well as the calorific value of the pellet was assessed. In addition, this research
also analysed the density of the pellet which will also affect the strength of the pellet and can lower transportation cost because of the low volume to handle and takes up less space for storage. The ability of the pellet to sustain its strength in long storage time is also important where the moisture content of the pellet will play a big role in maintaining pellet ability to avoid mould and breaking from external force. The reason is for the pellet to be stored for a certain amount of time without breaking down due to moisture content or experience moulding due to excess humidity and moisture content of pellet [7].

The particle size was in the range of 0.15 mm, 0.50 mm and 1 mm and a constant 15% moisture content which is chosen based on optimum moisture content for woody biomass that had been done in previous research [1]. Single hydraulic press pelletizer was used to produce pellet with different particle size and have different strength. The durability of the pellet was determined by using sieve shaker where the pellet was tested on its ability to withstand from breaking. For the process of biomass moisture content, the pellet gone through the process of using moisture analyser equipment which gave a pellet the precise moisture content that was used which is at 5%, 10%, and 15%, and moisture content with a constant particle size of 0.15 mm which is the smallest particle size from the scope. The constant particle size was chosen because from past researcher that had been done, smaller particle size used for the pellet would give a higher density and durability [3]. The different percentage of moisture content would affect the strength pellet as well as its density and energy content.

For the material of the pellet, wood from Khaya senegalensis plant was used to make the pellet because the research of pellet made from Khaya senegalensis plant have not been tested anywhere on any journal. The Khaya tree has a low weed potential and is highly used in medical area such as the fruits are used to help cure fever. The tree can also grow on multiple soil condition such as sandy, loamy and clay type of sand and can even grow in neutral or even acidic pH soil. The tree itself is also strong and can survive even in drought and the growth rate of the tree is also fast. Thus, in this research, the adaptability of the tree and the strength of the tree is taken as a positive characteristic to help in obtaining a pellet that might have a higher strength, density and calorific value from other pellet made from other type of wood or biomass.

2. Methodology

2.1. Biomass sample and equipment
The Khaya tree branches was collected and then chopped into smaller pieces using wood chipper. The shredded branch were then put into a laboratory blender to produce a small dust-like form of Khaya tree branch to be kept in a container for pelleting use. The collected Khaya Senegalensis tree is shown in figure 1 and figure 2 shows the equipment used in this experiment.

![Figure 1. Khaya Senegalensis tree.](image-url)
2.2. Particle Size
For pellet with different particle size. The grounded material was sieved using sieve shaker to obtain material with a particle size of 0.15 mm, 0.50 mm and 1.00 mm. The particle size that was used in this study was based on the available sizes from the sieve shaker and from past studies that had been conducted. The initial moisture content of the pellet was measured using moisture analyser as a fixed 15% moisture content is controlled for the pellets.

2.3. Pelletisation
The pellet was made by using single hydraulic press and 10 mm diameter pellet die. 1.720g ±0.005 grams of *Khaya Senegalensis* sample was mixed with binder and inserted into die compressed at 3 tons pressure of material was inserted into the mould for every pellet. The pellet consist of 75% *Khaya Senegalensis*, 10% binder and 15% moisture content in mass.

2.4. Pellet Properties Testing
Properties tests were conducted on each of the pellets produced to determine the properties of pellet which include the density, durability and the calorific value. Each properties was tested and performed accordingly in order to obtain an accurate and precise data.

2.5. Density test
Density test was performed according to ASTM D792-13 standard. Calculation was carried out by using the equation below:

\[ \rho = \frac{m}{v} \]  

where,

\( \rho \) is the density of pellet, g/cm²  
\( m \) is the mass of the pellet, g  
\( v \) is the volume of the pellet, cm²

2.6. Durability Test
The durability test was performed with international standard CEN/TC 335. EN 15210-1:2009. The pellet durability was determined using the equation below:

\[ DI = \left( \frac{m_f}{m_i} \right) \times 100\% \]  

where,

\( DI \) is durability index (%)  
\( m_f \) is the final mass of the pellet (g)  
\( m_i \) is the initial mass of the pellet (g)

2.7. Calorific value test
The calorific value was shown by the process of the heat that is released by the pellet after completed combustion occur. The combustion of the pellet was done through the usage of the bomb calorimeter.
The calorific value of the pellet is automatically measured and calculated by the bomb calorimeter using equation:

\[
Q = \frac{(m_1 + m_2)(T_c + (T_f - T_i)°C)(C_w))}{m_f}
\]

(3)

Where,

- \( Q \) is calorific value in kJ/kg
- \( m_1 \) is the mass of water in the calorimeter, kg
- \( m_2 \) is the water equivalent of bomb calorimeter, kg
- \( m_f \) is the mass of the pellet, kg
- \( T_c \) is the temperature correction for radiation losses
- \( T_f - T_i \) is the temperature difference, °C
- \( C_w \) is the specific heat of the water, J/kg/K

3. Results and Discussions

3.1. Durability

From figure 3, it can be seen that the pellet with a particle size of 0.15 mm has the highest durability percentage at 98.53% compared to 0.50 mm and 1.00 mm pellets. The durability of the pellet of 0.50 mm particle size pellet are 5.03% lower than 0.15 mm particle size. Pellet with a particle size 1.00 mm has 7.73% lower durability percentage than the pellet with 0.15 mm particle size. All the samples were at 15% of moisture content. On top of that, it can be seen that the error bars do not overlap with each other. This shows us that there might be a possibility that the difference between samples may be significant. By using single factor analysis of variance (ANOVA), the p-value obtained was less than 0.05. Thus, it can be said that particle size has a significant difference on the pellet durability.

![Figure 3. Durability of pellet from different particle size](image)

The reason for the pellet with 0.15 mm particle size having the highest durability percentage is that the surface area of the particle are larger thereby facilitated the inter-particle binding process. Thus, the compaction of the pellet will also increase as the binder can react more efficiently with the material [8]. In addition, material with smaller particle size fits together better to the fibre which will result in a more durable pellet [3, 9, 10]. The relationship between particle size and durability of pellet are inversely proportional to each other. The strength of the pellet will also increase with a decrease in particle size [2, 3].
3.2. Density

Figure 4 provides the density of pellets made from 0.15 mm, 0.50 mm and 1.00 mm particle sizes. It is apparent from this figure that 0.15 mm resulted in the highest density of pellet, followed by 0.50 mm and 1.00 mm particle sizes with a value of 1.07 g/cm³, 0.96 g/cm³, and 0.91 g/cm³ respectively. The difference in density between 0.15 mm and 0.50 mm particle size pellet are higher than 0.50 mm and 1.00 mm particle size pellet with a 10.3% decrease and 5.2% respectively. Also, from the same figure, these results indicate that the error bars do not overlap with each other. This indicate a clue that the data has a significant difference. From the single factor ANOVA, it was obtained that the p-value was lower than 0.05. With this, the null hypothesis is rejected. It was certain that biomass particle size has a significant difference on the density of pellet.

![Figure 4. Density of pellet from different particle size.](image)

Surface area of particle increases as the particle size decreases. This will cause the surface area to be able to undergo better compaction and binding between particle and binder [3]. In addition, as the surface area for compaction increase, the volume of the pellet will decrease as the mass are constant which results in a higher density value. In another paper by [11], the writer also obtained the same result. Furthermore, the writer also indicated that the density of pellet will differ for pellet made from different material even with the same particle size. This happen because of the composition of each material are different to each other.

3.3. Calorific Value

The results obtained from the calorific value test of pellets made from difference particle sizes are presented in figure 5. It can be seen that the calorific value of the pellet is highest for 1 mm particle size pellet following 0.50 mm and 0.15 mm particle size with a value of 16.503 MJ/kg, 15.954 MJ/kg, and 15.222 MJ/kg respectively. The error bars depicted in Fig. 5 do not overlap with each other thereby providing a clue that the value has a significant difference. By means of ANOVA single factor, it can be seen that the p-value was obtained to be lower than 0.05 with a value of 0.001. This shows that there is a significant difference on the calorific value of pellet made from different particle sizes.
It is interesting to note that the results obtained contradicts some research that had been done. In a study by [12], it was discussed that particle size of pellet is a factor that influence the calorific value of pellet. The calorific value of pellet with a lower particle size tends to increase as the particle size decrease as the particle size will influence the density of pellet which can be seen in 4.2.1. As the particle size of pellet decrease, the compaction of the pellet will also increase due to the higher surface area and therefore binding process of the particles becomes smoother. As the compaction of pellet increase, the effect of atmospheric humidity on the pellet to increase or decrease its moisture will also be lowered [13]. In the study, as the particle size of lignocellulose biomass pellet decreased from 0.60 mm, 0.45 mm and 0.25mm, the calorific value of the pellet increased with a value of 16.67 MJ/kg, 17.15 MJ/kg and 17.94 MJ/kg respectively. The contradiction between the results might occur due the difference in material that was used. The calorific value of pellet can differ with different material used even with the same particle size, procedure and moisture content. The composition of the material have a high impact towards the pellet. The carbon content, volatile matter and ash content of the material also affect the calorific value of pellet as supported in [14].

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