Khaya senegalensis and Leucaena leucocephala; Malaysian dedicated energy crop potential species

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Abstract. Dedicated energy crop (DEC) serves as a highly promising feedstock for heat and power apart from wastes. Established DEC plant species which include poplar, willow and eucalyptus possess special criteria such as fast growing, high biomass production per unit land area and can be planned in production. Locally available plants such as Leucaena leucocephala and Khaya senegalensis are identified among potential species which can be developed as our own DEC. Therefore, this research was conducted to assess the potential of Khaya senegalensis and Leucaena leucocephala as energy crop. Proximate analysis was executed to establish some important quality of the biomass sample which were moisture content, volatile matters, ash content, and carbon content. Biomass sample was then pelletized and subjected to density and durability testing to evaluate the pellet quality produced. Interestingly, it was found that Khaya senegalensis and Leucaena leucocephala biomass have strong potential to be industrialised as our own dedicated energy crops. The calorific value of both biomass are as good as other established energy crops thereby enlisting these two plant species as Malaysian energy crop.

1. Introduction
Global climate change due to the increasing usage of fossil fuel incite the intensive research and development of sustainable renewable energy production. The usage of renewable energy can lessen the dependency towards fossil fuel and consequently decrease the greenhouse gas emissions level. On that reason, the European Union had set the targets to increase the consumption of energy generates by renewable sources to 20% by 2020. Not just that, the EU target to achieve 40% lower GHG emission as compared to 1990 level as part of their green energy plan [1].

Malaysia take the first serious step in exploring and implementing energy from renewable resources on 2001 by introducing the Small Renewable Energy Programme (SREP). However, this programme had neglected the biomass contribution as one of the most prominent renewable sources. However, in 2011, Malaysia government established the Sustainable Energy Development Authority (SEDA) as the representative for monitoring and managing the renewable energy industries. It is forecasted that the renewable energy contribution will increase drastically to 73% (21.4GW) in 2050 from 5.5% (985 MW) in 2015. Interestingly, renewable energy from biomass is estimated to contribute about 38.5% (800MW) of total energy generated from renewable resources in year 2020 as stated in the national biomass strategy 2011 [2].
According to The European Environmental Agency, 13% out of 1.8 billion tons of European energy consumption in the 2020 will be contributed by biomass industry. In conjunction with that, it is estimated that the demand for biomass as a feeding material for heat and power will be amplified to 5-7 billion tons in 2050 [3]. Biomass is among the great source of renewable energy considering the ability to replanted and very low quantity of CO₂ emissions [4]. Among the sources of biomass such as agricultural waste, industrial waste and forestry waste, the dedicated energy crops showed some assuring criteria as sustainable resource of biomass energy in term of production and energy. Dedicated energy crop (DEC) is referred to plant species that are specifically planted for energy production purposes. Poplar, willow, eucalyptus and miscanthus are among the example of established DEC that have been commercially produced for bioenergy market. These plant species possess special criteria such as fast growing, easy to produce, high biomass production per unit land area and can be planned in production.

We are fortunate that in Malaysia we have several numbers of plant species that have similar agronomic characteristics as of the established western dedicated energy crop. Plants such as petai belalang (Leucaena leucocephala), khaya (Khaya senegalensis), akasia (Acacia mangium), sentang (Azadirachta excelsa) and Gliricidia spp. are among potential species which can be developed as our own DEC. In terms of agronomic practices and pest and diseases management of Leucaena leucocephala and Azadirachta excelsa are well-established. Similarly, though it was not systematically worked out and gathered, some basic information on biomass energy characteristics is available [7]. Besides, initial work on pelletization of biomass of these two plant species has been explored [8]. Another potential plant species that has DEC promising characteristic but less explored is Khaya senegalensis. Therefore, this research was conducted to evaluate the potential of Khaya senegalensis as energy crop together with the Leucaena leucocephala biomass.

2. Methodology

2.1 Biomass sample
The matured Khaya senegalensis and Leucaena leucocephala plants were harvested from available plant at Institute of Sustainable Agrotechnology (INSAT), UniMAP. The plants were allowed to sun dry for 1 week before ready to shred using shredding machine available at the lab of Faculty of Engineering Technology. The shredded biomass was ground to obtain smaller particle size of the biomass sample and was stored in air tight container for further use.

2.2 Biomass characterization
Proximate analysis was performed to establish some important quality of the biomass sample which were moisture content, volatile matters, ash content, and carbon content. The moisture content was determined using ASTM D 4442-07 standard method for wood and wood-based materials method. The weighed sample will be dried in the oven at 105°C for 24 hours. The moisture was calculated by the difference between initial and final weight. The ash percentage will be determined by igniting the sample at 575°C for 5 hours in the furnace (ASTM-E1755). The volatile matter will be quantified using ASTM-E872 method where the sample will be burned at 950°C for 7 minutes. The total fixed carbon content will be calculated using the following equation:

\[
FC = 100 - (\% MC + \% VM + \% AC)
\]  

Calorific value of the samples was determined by a bomb calorimeter as stated in the ASTM Standard D 5865 procedure. Approximately 0.5 g of the sample was weighed and placed in a crucible immersed in distilled water inside the bomb calorimeter. The calorific value was recorded as MJ per kg of the biomass sample.

2.3 Pelletization of Khaya senegalensis and Leucaena leucocephala biomass
The biomass sample was pelleted using the single press pellet available at Faculty of Engineering Technology. The pellet was made with different particle size of both biomasses to quantify the pellet density and durability. Another experiment was performed to determine the effect of blending ratio of *Khaya senegalensis* and *Leucaena leucocephala* biomasses on the physical quality of the pellet.

### 2.4 Pellet density

The particle density was determined by dividing the weight of the pellet over the volume of it. Since the pellets are cylindrical, the following equation was used to determine the volume.

\[
V = \frac{\pi}{4} D^2 L
\]

where V is the volume, D is the pellet diameter, and L is the pellet length.

### 2.5 Pellet durability

The mechanical durability of the pellet produced was determined according to the international standard CEN/TC 335. EN 15210–1:2009. The sample was weight and sieved on a 3.15 x 10^-3m sieve at 50 revolutions per minute (rpm) and will be rotated 500 times. The durability was calculated based on the difference in the weight of the residue on the sieve and the initial weight of the pellets.

\[
DU = \left[100\% - \left(\frac{M_a - M_e}{M_e}\right) \times 100\%\right]
\]

where, DU is durability, M<sub>a</sub> is the mass of pre-sieved pellets before the tumbling treatment in grams and M<sub>e</sub> is the mass of sieved pellets after the tumbling treatment in grams.

### 3. Result and discussion

#### 3.1 Leucaena leucocephala

*Leucaena leucocephala* is an easy growing leguminous plant that can be found almost everywhere in Malaysia. It can be planted on less fertile soil, has the ability to coppice and the yield is in the range of 91-99 % after coppiced. Therefore, *Leucaena leucocephala* has a strong potential to become a dedicated energy crop [9] [10]. The *Leucaena leucocephala* plant is originated from Central America and Mexico. It has been used as a source of animal food, stakes in construction industry, firewood, and edible pods for industrial and non-industrial purposes. Nevertheless, in the recent years, *Leucaena leucocephala* has become among the most promising candidate in biomass industry as a source of high quality biomass feedstock [11] [12] [13].

#### 3.2 Khaya senegalensis

*Khaya senegalensis* is known as timber plant originated from Africa. According to forestry department peninsular Malaysia, this species is a fast growing crop that can reach 35m in height. In Malaysia, despite has been planted for timber production it also has been introduced as landscape and shade tree. Compare to *Leucaena leucocephala*, this species not yet introduced as strong candidate for energy crop. Based on the data gathered, this species has some potential characteristic to be listed as future energy crops. One of the most prominent criteria is the fast growing plant and can be cultivated on marginal soil. As stated by [10], with some imposition of fertilizer the plant can reach about 400 cm in height and produce about 18 kg per plant just in one year. Therefore, further study on its potential as energy crop must be established. In this experiment, the proximate analysis data and calorific value of raw *Khaya senegalensis* biomass has been studied. Another important criterion is the biomass can be densified into pellet or briquette form. Hence, the preliminary experiment has been conducted to quantify the density and durability of *Khaya senegalensis* pellet.

#### 3.3 Biomass characterization

The proximate analysis and the calorific value of the samples is shown on the table 1. From the proximate analysis data, it was found that there is some difference in physical characteristics between
both species. The higher moisture content in *Leucaena leucocephala* biomass shows that the structure of the wood is more fibrous than *Khaya senegalensis* wood. The high moisture content of the biomass feedstock may give numerous bad effects. It will increase the storage and transportation expenses. In addition, high moisture of the biomass will lead to enhancement of trace elements and heavy metals leaching process during storage and biochemical processing. Furthermore, the presence of high moisture also will increase the microbial activities and will be resulted in the deterioration by biological degradation of the biomass. During biomass thermal conversion, the moisture could possibly give a negative impact on the biomass combustion characteristics; poor ignition, reduce the combustion temperature and efficiency. These will be resulted in low calorific value of the biomass. Not just that, the moisture also will affect the grind capacity of the biomass. It is harder to grind the biomass with high moisture as it also can break the grinder blade [15] [16].

### Table 1. Proximate analysis data and calorific value of *Khaya senegalensis* and *Leucaena leucocephala* biomass.

| Scientific name             | Proximate analysis (%) | Calorific value (MJ/kg) |
|-----------------------------|------------------------|-------------------------|
|                             | Moisture content       | Ash content            | Volatile matters | Carbon content |          |
| *Khaya senegalensis*        | 26.06                  | 29.37                  | 32.80            | 37.83          | 16.11    |
| *Leucaena leucocephala*     | 33.83                  | 9.22                   | 88.47            | 2.30           | 16.48    |

Ash content in the biomass refers to the residue left the sample is completely combusted. The main components of biomass ash is the oxide from aluminium, calcium, titanium, silica, magnesium, iron, sodium and potassium. The information of the biomass ashes is important to make a good design of boiler or gasifier. It also will help in the management of the deposits inside the thermochemical conversion facility [11]. In general, feedstock with high ash content is considered as low quality as it will directly influence the combustion performance. In addition, the leftover ash inside combustion chamber will incur more disposal cost [12]. Even though the ash content in the biomass feedstock is much lower than in coal, it contains high amount of alkaline and alkaline earth metals. This composition, make the ash content in the biomass feedstock more complex and can cause a major problems in thermal conversion systems such as corrosion, deposition agglomeration, , slagging and fouling [13]. The ash content of *Khaya senegalensis* relatively high as compared to the *Leucaena leucocephala* biomass. Therefore, it is suggested that the biomass is pre-treated to reduce the ash content.

The volatile matters and carbon content is interrelated. Biomass with high volatile matters will possesses less carbon content and vice versa. As can be seen in Table 1, *Leucaena leucocephala* biomass has high volatile matters and low carbon content as compared to *Khaya senegalensis* biomass. The volatile matter is the fuel fraction excluding moisture of the biomass after has been combusted at high temperature in the absence of air. It generated from organic and inorganic components of the biomass. It comprises from combustible part such as CO, and H₂ and also non-combustible part (CO₂, SO₂, NOₓ, H₂O, and SO₃). The biomass with high volatile matter is easy to ignite at low temperature, indicating high reactivity and enhancing the combustion process. In-general the amount of volatile matter is depending on the process parameters such as heating rate, temperature and residence time. However, in the proximate analysis, the volatile matter is measured in the controlled environment such as furnace with the standard temperature and time [14]. Fixed carbon is the amount of the biomass.
remaining after deducting the volatile matter and ash content of the biomass. The influence of fixed carbon on the energy characteristics of the biomass is complex. The information on the elemental composition is needed to quantify the effects [11].

The calorific value of *Khaya senegalensis* and *Leucaena leucocephala* are considerably high for a raw biomass. Miscanthus, a quite establish energy crops is reported to has around 17MJ/kg calorific value and the value is comparable to other potential energy crops such as switchgrass and giant reed [15].

Calorific value refers to the amount of heat produced by complete combustion per unit weight or volume of a biomass. The value is really important and represent the efficiency of the biomass as energy source. The main challenge in biomass energy is the energy density of biomass is lower as compared to the fossil fuel. These phenomena are much contributed by the physical and biochemical characteristics of the biomass. It is known, raw biomass possesses low bulk density and high moisture content. These properties are reported give strong influence on the calorific value of the biomass.

The volatile matters and fixed carbon composition also have major effect on the biomass calorific value. High volatile matters reflect lower fixed carbon content. Fixed carbon has been identified to affect the calorific value. Nevertheless, the high volatile matters not always exhibit the low calorific value as their relationship is rather complicated. The high volatile matter in biomass pellet does not consistently gives high calorific value and vice versa. This may happen due to the volatile matter composition that contains combustible gases such as CO₂ and H₂O. In addition, ash content in pellet forming material also will affects the calorific value. The ash in the pellet requires certain amount of energy for thermal breakdown and phase transition into inorganic compounds that will results in the reduction of the calorific value [16].

### 3.4 Pellet quality

The densified form of biomass is more preferable in biomass energy market as it can save more cost on transportation and storage. Besides calorific value, the density and durability is important criteria that represent the physical quality of biomass pellet. Figure 1 shows the *Khaya senegalensis* and *Leucaena leucocephala* biomass pellet density of 0.2 mm, 0.3 mm and 0.5 mm particle sizes.

![Figure 1. Pellet density of different particle size of Khaya senegalensis and Leucaena leucocephala biomass](image)

It was found that in general pellet made by *Khaya senegalensis* biomass possess higher density compare to the *Leucaena leucocephala* biomass pellet. This give some advantage for *Khaya senegalensis* biomass as the higher pellet density generally contain more energy. Another important
finding is the bigger feedstock particle size has the higher pellet density and the result is more prominent on Khaya senegalensis pellet. Khaya senegalensis higher pellet density must be contributed from its physicochemical characteristics. Moisture and lignin content of the biomass can give major influence on its pellet density. Low moisture content and high lignin composition is the most preferable biomass as it can produce high density pellet [17].

Pellet durability is another important criterion of a good pellet. Durable pellet is easier to be transported and stored. Good quality pellet must has more than 97.5% durability [17]. Figure 2 shows the durability of the Khaya senegalensis and Leucaena leucocephala pellet made from different particle size of the biomass.

![Figure 2. Durability of Khaya senegalensis and Leucaena leucocephala biomass pellet.](image)

It was found that the durability of the pellets is fairly good. Moisture content [18], cellulose content [19], binders amount and types [20], and physical characteristics of the biomass [21] are among the prominent factors in determining the pellet durability.

4. Conclusion
Based on the study, it was found that Khaya senegalensis and Leucaena leucocephala biomass have strong potential to be developed as our own dedicated energy crops. The major factor for a crop to be listed as energy crop is calorific value and the calorific value of both biomass are as good as other established energy crops. However, more data are needed to have better understanding on its physicochemical characteristics of these biomass as it can give strong influence on its quality.

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