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Moringa oleifera Seeds Potential as Biofuel via Thermal Conversion Method Based on Morphological and Chemical Content Evaluation

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Abstract. The 26th UN Climate Change Conference of the Parties (COP26), last held in Glasgow, Scotland, in November 2021, encouraged countries to keep global warming below 1.5 degrees Celsius. On the other hand, fossil fuels are still dominant as a primary source for power generation. In order to keep the temperature target viable, clean and renewable fuel is needed immediately. Biomass is a promising alternative for future energy sources, which has several advantages compared to wind and solar power generators. Atmospheric carbon dioxide is absorbed by biomass for its growth, making it a carbon-neutral fuel. *Moringa oleifera* (MO) has big potential compared to other lignocellulosic biomass based on its growth resilience in a wide range of climates. MO seeds contain highly valuable chemical products in the form of lipids and carbohydrates that can be converted into fuel using pyrolysis. Morphology and surface chemical content testing using SEM-EDX show that the average MO seed particle has spherical geometry, which is desirable because it has the smallest contact area compared to other shapes. Chemical analysis concludes that MO seeds have 73 and 23 wt.% carbon and oxygen, respectively. Trace inorganic elements are also present, such as Mg, Al, P, S, K, and Ca, which can be beneficial for the thermal conversion process because they are able to provide a catalyst effect and can be further utilized as fertilizer.

1 Introduction

Due to time-consuming forming mechanisms, fossil-derived energy sources such as coal, crude oil, and natural gas are considered nonrenewable [1]. However, fossil fuel is still a major energy source. According to the United Nations Department of Economic and Social Affairs [2], fossil fuel combustion generates carbon emissions, which has a negative effect

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on the environment, thus resulting in global warming [3]. Global temperature rises up 2 ˚C annually [4]. Global net carbon emissions in 2015 reached 32,29 billion tons.

Energy transformation from fossil to clean and sustainable sources is essential to prevent further carbon emissions. Paris Agreement is a global effort to limit climate temperature increase below 1,5 °C/annum [5]. Raihan *et al.*[6], stated that Indonesia agreed to cut carbon emissions by 40% in 2030 and then net-zero emissions in 2060. As an equatorial nation, biomass is one of the prominent energy sources due to its availability and carbon-neutral characteristics [7]. Biomass originating from terrestrial plants is categorized into 2nd-generation biomass, which does not interfere with human food sources. Cellulose, hemicellulose, and lignin are the main component of the 2nd-generation biomass [8]. *Moringa oleifera* (MO) is a potent biomass to be utilized as a future energy source.

MO typically grows in tropical climates. However, MO has good resilience in drought conditions, resulting in its great availability [9]. MO contains high lipid content, especially in their seeds, which are 33.3-55.7 (wt,%), higher than other *Moringa* species. Based on lipid content, MO seeds are able to be converted into bio-oil or biodiesel [10]. Titiloye *et al.* [11] also suggest that MO seeds can be utilized to generate biogas. Ultimate analysis shows that MO contains 6.49 (wt,%) hydrogen, which is relatively higher compared to other 2nd-generation biomass.

MO seeds have an obvious advantage for biofuel sources. In the present work, MO seeds were investigated using SEM-EDS to obtain particle shape and surface chemical content, which is essential to predict the thermal conversion mechanism and its product.

2 Material and method

2.1 Material

MO seeds were purchased from herb stores in Surabaya, where they were collectively harvested from the East Java region. MO seeds were separated from their shells and then crushed using a grinder to increase surface area. Electric ovens were used to remove excess moisture at 60°C for 24 hours. The powder of dried MO seeds was then filtered using a mesh-60 sieve to obtain uniform particle size. Figure 1 describes the overall process of sample preparation.

Fig. 1. MO seeds sample preparation

2.2 Method

2.2.1 Characterization

An SEM-EDS test was carried out using FEI Inspect S50 fitted with AMETEK EDAX TSL x-ray analysis. Scanning electron microscopy (SEM) images were used to justify the particle shape of MO seeds. Chemical content in particles' surface was obtained by energy dispersive X-ray spectroscopy (EDS) result.

3 Result and discussion

3.1 Particle shape analysis

Figure 2 depicts the MO seeds' SEM image at various magnifications, and Figure 3 shows particle classification based on its shape according to the reference [12]. MO seeds have relatively uniform spherical shapes and are likely to agglomerate with other particles due to their lipid content [10]. Lu *et al.* [13] mentioned that particle shape directly affects the thermal conversion reaction rate. Spheres have a low surface area-to-volume ratio, resulting in slower heat and mass transfer during thermal conversion due to a longer average path length for heat and volatile content than aspherical shape. Near-spherical particles also yield lower volatility due to inhibited mass transfer.

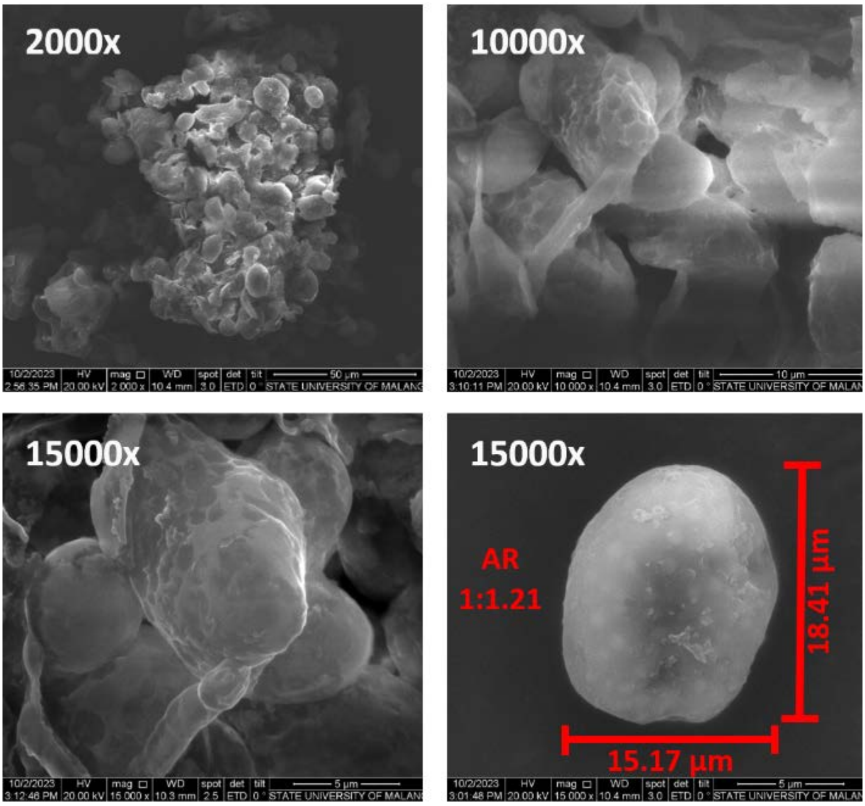


Fig. 2. MO seeds SEM image at various magnifications

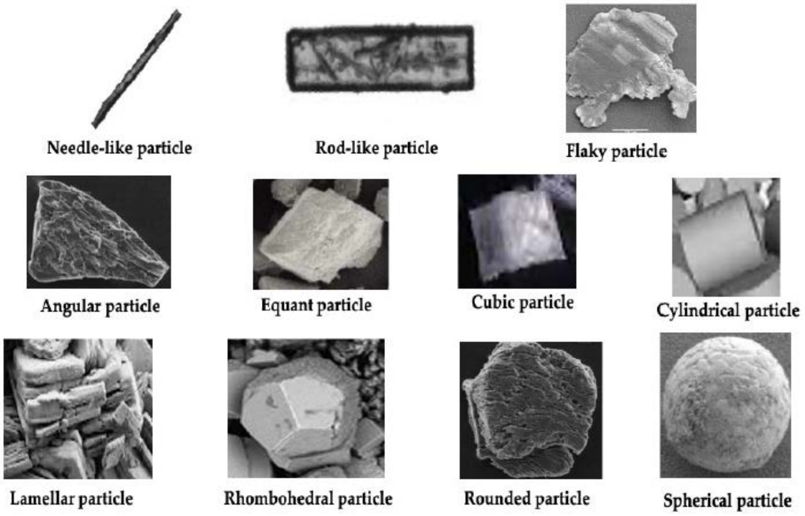


Fig. 3. Various shapes of particles according to reference [12]

The particle aspect ratio (AR) value is obtained by dividing particle width by height; this parameter is often used to justify the thermal conversion mechanism. Okekunle *et al*. [14] stated that if the particle aspect ratio increased, more heat entered from a larger surface area, resulting in uniform temperature distribution and vice versa. However, based on Figure 2, the MO seeds particle has an aspect ratio of 1:1.21, where it has a larger temperature gradient compared to a higher aspect ratio particle due to its relatively uniform thickness resulting in primary tar release through surface hotspot when intra-particle conduction occurs as visualized by Figure 4 (a). The higher temperature in the hotspot area reduced convective heat transfer, which led to a decrease in the decomposition reaction rate [15]. Leftover tar undergoes intramolecular condensation and aromatization reaction, forming char product[16,17]. MO seed particles tend to have hotspot areas in the more extended region due to their larger surface area (Figure 4 (b)).

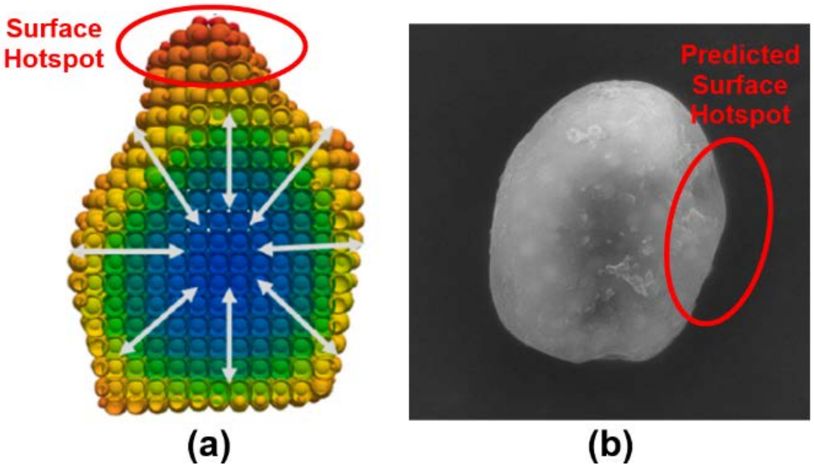
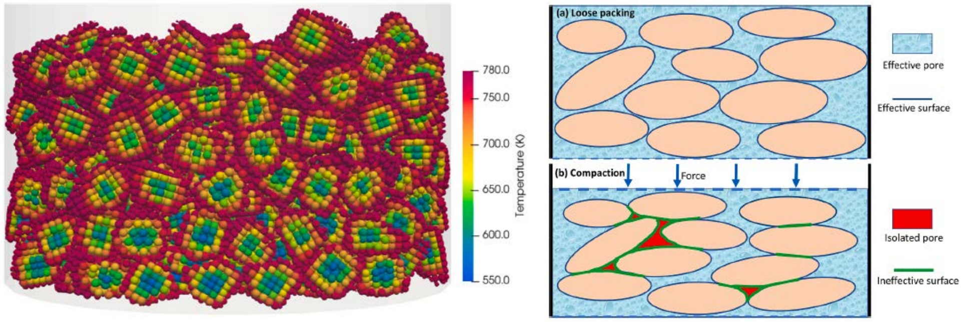


Fig. 4. (a) Intra-particle conduction[15] and (b) predicted surface hotspot of MO seeds



(a) **(b)**

Fig. 5. (a) Inter-particle conduction[15] and (b) loose packing and compaction effective surface comparison[18]

Inter-particle effective surface area positively correlates with chemical reaction rate, where higher effective surface area promotes accelerated reaction [18]. Figure 5 (a) shows angular and flat particles tend to have a high contact area between particles, which promotes inter-particle conduction [15]. However, large contact areas also cause surface blocking, which reduces mass transfer during the thermal conversion process. On the other hand, Figure 5 (b) shows that spherical particles have the lowest contact area, promoting better volatile release and enhancing liquid and/or gas products during pyrolysis. In accordance with Bielecki *et al.*[19] findings where densified pyrolysis samples, representing a larger contact area, yield more char than loose packing particles.

Particle shape analysis suggests that MO seed particles tend to form char products during the pyrolysis process due to their spherical shape. However, char yield can be minimized by loading loose packing feedstock to prevent surface blockage and enhance mass transfer during thermal conversion.

3.2 Chemical content analysis

Figure 6 shows a spectrogram of two different MO particles. The elemental compositions are listed in Table 1. MO seeds have eight detected elements. These elements mostly originated from MO growth habitat, which is correlated with metabolism and nutrition [20]. Carbon and oxygen content are dominant elements, with 77.6 and 19.7 (wt,%), respectively. Calorific value has a positive correlation with carbon percentage due to its chemical bond energy potential. On the other hand, oxygen content is less desirable because it is related to the presence of moisture [21]. Fuels quality is often determined using the O/C ratio, where smaller values represent higher calorific values. MO seeds have a mean O/C ratio of 0.25, which is comparable with lignite at 0.215 [22].

Trace element of MO seeds was detected dominated by phosphor and potassium at 0.55 and 0.4 wt., %, respectively. Those two elements were associated with MO macronutrients [23]. The trace element is the main factor of the ash-forming mechanism during the thermal conversion process [24]. Based on its boiling point and operation temperature, trace elements can be categorized into fly and bottom ash precursors [25]. The boiling point of each element is listed in Table 2. Al-rumaihi *et al.* [26] conclude that pyrolysis temperature can be tuned to obtain a desired product with a char optimal temperature of 300-380℃ and liquid/gas at 400-800℃. In a char production scenario, phosphorus is likely to form fly ash, and the other element might create bottom ash. However, ash content can be re-purposed as fertilizer to enhance plant growth [27]. Chemical analysis suggests that MO seed has the potential to be used as future fuel through thermal conversion methods due to its comparable O/C ratio with fossil fuel and relatively low ash content.

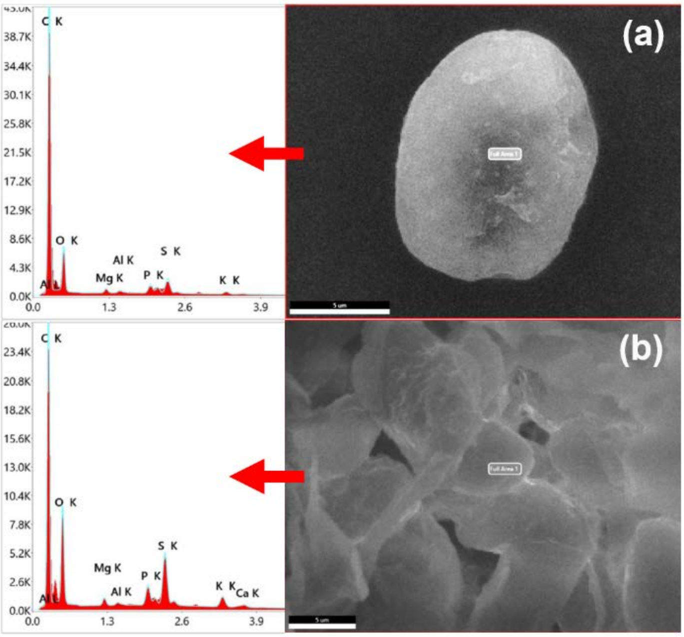


Fig. 6. EDS spectrogram of (a) single and (b) agglomerates of MO seeds

Table 1. Elemental composition analysis of MO seeds

Scanning	Elemental composition (wt., %)							
	C	O	Mg	Al	P	S	K	Ca
1	82.1	16.3	0.2	0.1	0.4	0.8	0.2	-
2	73.1	23.1	0.3	0.1	0.7	2	0.6	0.2
Mean	77.6	19.7	0.25	0.1	0.55	1.4	0.4	0.2

Table 2. Inorganic element boiling point [28]

Elements	Boiling Point (℃)
Aluminum (Al)	2470
Magnesium (Mg)	1110
Phosphorus (P)	280.2
Sulfur (S)	445.2
Potassium (K)	774
Calcium (Ca)	1487

4 Conclusion

Moringa oleifera seeds have spherical geometry with a 1:1.21 aspect ratio that has a large temperature gradient limiting tar decomposition rate and tend to form char products during pyrolysis. Effective surface contact between spherical particles is lowest compared to other shapes, therefore enhancing mass transfer. Chemical content analysis indicates that MO seeds contain relatively high carbon (>77.6%) and moderate oxygen (<19.7%) on average, resulting in an O/C ratio of 0.25, which is comparable with lignite coal at 0.21. Ash-forming chemical content was dominated by phosphorus and potassium at 0.55 and 0.4 (wt,%), respectively. Sulfur and phosphorus tend to form fly ash due to its relatively lower boiling point compared to other trace elements. High boiling point materials such as Mg, Al, K, and Ca tend to become bottom ash. Based on those findings, MO seeds have the potential to be converted into liquid and/or char products via the pyrolysis process. Ash-forming elements are relatively low and can be re-purposed as fertilized.

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