Investigating the Physicochemical Characteristics of *Moringa oleifera* Leaves: Revealing its Viability as an Alternative Fuel Source

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Abstract. This study explores the physicochemical properties inherent in *Moringa oleifera* leaves, aiming to uncover their potential as a promising alternative fuel source. The research involves a comprehensive investigation into the unique attributes of these leaves, shedding light on their suitability for serving as an eco-friendly and sustainable energy option. By examining key physicochemical characteristics, this study aims to contribute valuable insights to the ongoing discourse on diversifying fuel alternatives and promoting environmentally conscious energy solutions. The samples underwent proximate analysis to achieve this objective, revealing specific contents of volatile matter, fixed carbon, and ash at 76.23%, 12.76%, and 11.01% (wt%, dry basis), respectively. Additionally, the leaves exhibit a gross calorific value of 4702 kcal/kg (19.67 MJ/kg). The ultimate analysis further underscores the high fuel potential of the *Moringa oleifera* leaves, with a carbon content of 47.40% (wt%, dry basis). Notably, the leaves present low undesirable levels of nitrogen and sulfur, measuring at 3.68% and 0.67% (wt%, dry basis), respectively.

1 Introduction

In response to the escalating global demand for sustainable and eco-friendly energy sources, researchers have been fervently exploring novel alternatives to traditional fossil fuels [1,2]. *Moringa oleifera*, a versatile plant with a rich history of applications in various fields, has recently emerged as a potential candidate for alternative energy production [3–8]. This study aims to investigate the physicochemical characteristics of *Moringa oleifera* leaves, unveiling their viability as a promising alternative fuel source. Exploring this botanical resource aligns

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with the urgent need to diversify energy options and mitigate the environmental impact of conventional energy production.

Moringa oleifera, often referred to as the "drumstick tree" or "miracle tree," has garnered attention due to its fast growth, adaptability to diverse climates, and nutrient-rich composition. Beyond its traditional uses in medicine, nutrition [9], and water purification [10–13], the plant's leaves possess intriguing attributes that warrant examination for their potential role in the energy sector [14]. This research endeavors to contribute valuable insights to the ongoing discourse on sustainable energy solutions by delving into the unique physicochemical properties of *Moringa oleifera* leaves.

The study employs a comprehensive approach, incorporating proximate and ultimate analyses to characterize key components of the leaves. Proximate analysis reveals specific contents of volatile matter, fixed carbon, and ash, shedding light on the combustion characteristics. Furthermore, the investigation extends to the gross calorific value, a crucial parameter in assessing the energy content of a potential fuel source. The ultimate analysis, with a focus on elemental composition, provides deeper insights into the carbon content and the presence of undesirable elements such as nitrogen and sulfur.

As the world faces the challenges posed by climate change and finite fossil fuel resources, the pursuit of sustainable and environmentally conscious energy alternatives becomes imperative. This research seeks to illuminate the potential of *Moringa oleifera* leaves as a renewable and eco-friendly energy source, offering a promising avenue for further exploration in the quest for a greener energy future.

2 Material and method

2.1 Material

Moringa oleifera leaves were acquired from an herbal store in Surabaya, sourced collectively from the East Java region. The leaves were meticulously crushed using a grinder to enhance the sample's surface area. Subsequently, electric ovens were employed to eliminate the moisture, maintaining a temperature of 45℃ for a duration of 4 hours. The resulting dried sample powder underwent filtration through a mesh-60 sieve, ensuring a uniform particle size. Figure 1 describes the overall process of sample preparation.

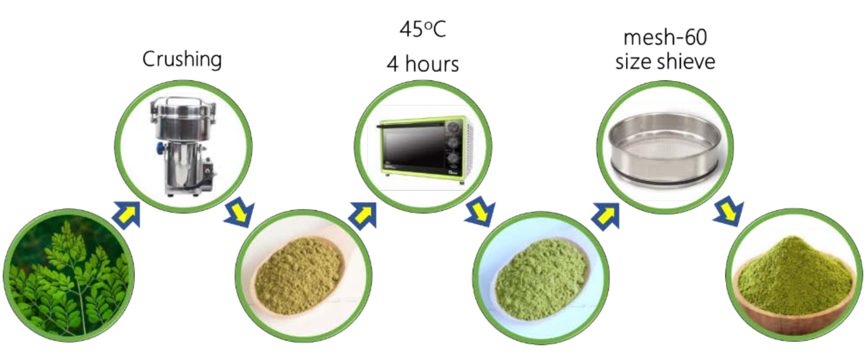

Fig. 1. *Moringa oleifera* leaves sample preparation

2.2 Method

2.2.1 Physical properties and gross calorific value evaluations

The physical attributes of *Moringa oleifera* leaves encompass moisture content, volatile matter, fixed carbon, ash content, and gross calorific value. These respective parameters were individually assessed using the following standards: ASTM E871 - 82, ASTM E872 - 82, ASTM D3172 - 13 (2021)e1, ASTM D1102 - 84, and ASTM D5865/D5865M - 19. For the purpose of proximate analysis, around 45 grams of leaf samples were subjected to testing to determine the physical properties and heating value of the material.

2.2.2 Analysis of elemental composition

The elemental composition of *Moringa oleifera* leaves, encompassing Carbon, Hydrogen, Nitrogen, Oxygen, and Sulfur, was evaluated using established methodologies outlined in ASTM D5373 - 21 Method A, ASTM D5373 - 21 Method A, ASTM D5373 - 21 Method A, ASTM D3176 - 15, and ASTM D4239 - 18e1 Method A, respectively. About 45 grams of leaf samples underwent ultimate analysis to unveil and characterize their chemical attributes.

3 Result and discussion

3.1 Physical properties and gross calorific value

The physical properties of *Moringa oleifera* leaves, as outlined in Table 1, provide valuable insights into their suitability as a potential alternative fuel source. Each parameter analyzed, including total moisture, volatile matter, fixed carbon, ash content, and gross calorific value, is crucial for understanding the combustion characteristics and energy potential of these leaves.

The total moisture content of *Moringa oleifera* leaves, measured at 5.67% (ar), is a critical factor in assessing their combustion efficiency. The low moisture content indicates that these leaves possess favorable conditions for combustion, as excess moisture can hinder the efficiency of the burning process.

The volatile matter content, measured at 71.91% (ar) and 76.23% (db), underscores the combustible components that can vaporize during the initial stages of combustion. This high volatile matter content suggests that *Moringa oleifera* leaves have the potential to ignite readily, contributing to their feasibility as a fuel with efficient combustion characteristics.

The fixed carbon content, documented at 12.03% (ar) and 12.76% (db), represents the solid carbonaceous residue left after volatile matter has been expelled during combustion. This parameter is crucial in assessing the leaves' ability to sustain combustion, providing stable heat output.

The ash content, measured at 10.39% (ar) and 11.01% (db), signifies the inorganic residue remaining after complete combustion. While ash is an inevitable byproduct, the levels observed indicate the leaves' potential for minimal ash production, contributing to cleaner and more efficient combustion processes.

The gross calorific value, an essential energy content indicator, is recorded at 4702 kcal/kg (19.67 MJ/kg, db). This value signifies the potential heat released during the combustion of *Moringa oleifera* leaves. The higher calorific value suggests that these leaves hold promise as a calorifically rich alternative fuel source, contributing to sustainable energy practices.

Table 1. Physical properties and gross calorific value of *Moringa oleifera* leaf

Parameters	Unit	ar*	db**	Test Method
Total moisture	% wt	5.67	---	ASTM E871 - 82 (2019)
Volatile matter	% wt	71.91	76.23	ASTM E872 - 82 (2019)
Fixed carbon	% wt	12.03	12.76	ASTM D3172 - 13 (2021)e1
Ash content	% wt	10.39	11.01	ASTM D1102 - 84 (2013)
Gross calorific value	kcal/kg	4435	4702	ASTM D5865/D5865M - 19

*ar: as received, **db: dry basis

The distinctions between "as received" (ar) and "dry basis" (db) measurements in the presented parameters highlight the influence of moisture content on the overall physical properties of *Moringa oleifera* leaves. As received values account for the leaves' inherent moisture, while dry basis values provide insights into the composition without the moisture factor.

The comprehensive analysis of *Moringa oleifera* leaves' physical properties provides a robust foundation for considering them as a promising alternative fuel source. The results, in accordance with established standards, emphasize the leaves' potential for efficient combustion and highlight their significance in the pursuit of sustainable and eco-friendly energy solutions.

3.2 Elemental compositions

The elemental composition of Moringa oleifera leaves, detailed in Table 2, plays a pivotal role in understanding the intrinsic properties that influence their potential as a bioenergy feedstock. Each parameter, including carbon, hydrogen, nitrogen, oxygen, and total sulfur, provides valuable insights into the leaves' chemical makeup and combustion characteristics.

Carbon, a fundamental element in biomass, constitutes a significant portion of Moringa oleifera leaves, with percentages of 44.71% (ar) and 47.40% (db). This high carbon content indicates the leaves' potential as a carbon-rich feedstock for energy production, emphasizing their suitability for combustion processes.

Hydrogen, a crucial component influencing the calorific value of biomass, is observed at percentages of 5.16% (ar) and 5.47% (db). The presence of hydrogen contributes to the leaves' energy content, enhancing their potential as a bioenergy source.

Nitrogen, though present in smaller quantities, is a parameter influencing combustion characteristics. The percentages of nitrogen are recorded at 3.47% (ar) and 3.68% (db), indicating the leaves' nitrogen content, which can impact combustion efficiency and emissions during burning.

Oxygen, an integral component in biomass, is observed at percentages of 29.97% (ar) and 31.77% (db). The oxygen content is crucial for the leaves' combustibility, affecting their reactivity during combustion processes.

The total sulfur content, measured at 0.63% (ar) and 0.67% (db), is an essential parameter influencing the environmental impact of combustion. The low sulfur content observed in Moringa oleifera leaves suggests their potential as a low-sulfur bioenergy feedstock, minimizing emissions of sulfur dioxide during combustion.

The distinction between "as received" (ar) and "dry basis" (db) values is essential in interpreting the elemental composition, as it accounts for the inherent moisture content. The dry basis values provide insights into the composition without the influence of moisture, offering a more accurate representation of their chemical makeup.

The elemental composition analysis of *Moringa oleifera* leaves showcases their potential as a bioenergy feedstock with favorable attributes, including high carbon content, moderate hydrogen content, and low sulfur content. These characteristics position *Moringa oleifera* leaves as a promising candidate for sustainable and eco-friendly energy production.

Table 2. Element compositions of *Moringa oleifera* leaf

Parameters	Unit	ar*	db**	Test Method
Carbon	% wt	44.71	47.40	ASTM D5373 - 21 Method A
Hydrogen	% wt	5.16	5.47	
Nitrogen	% wt	3.47	3.68	
Oxygen	% wt	29.97	31.77	ASTM D3176 - 15
Total Sulfur	% wt	0.63	0.67	ASTM D4239 - 18e1 Method A

*ar: as received, **db: dry basis

4 Conclusion

The comprehensive analysis of the physical properties and elemental composition of *Moringa oleifera* leaves underscores their potential as a versatile and sustainable bioenergy feedstock. The examination of physical properties, including total moisture, volatile matter, fixed carbon, ash content, and gross calorific value, reveals promising attributes for their utilization as an alternative fuel source. The low total moisture content indicates favorable conditions for combustion. The high volatile matter content suggests the leaves' potential to readily ignite. The fixed carbon content ensures stable heat output during combustion, while the low ash content signifies the potential for minimal ash production, contributing to cleaner and more efficient combustion processes. The gross calorific value, recorded at 4702 kCal/kg (19.67 MJ/kg, db), highlights the leaves' substantial energy content, positioning them as a calorifically rich alternative fuel source for sustainable energy practices. The elemental composition analysis further reinforces the leaves' suitability for bioenergy production. With a low sulfur content of 0.63% (ar) and 0.67% (db), *Moringa oleifera* leaves emerge as a low-sulfur bioenergy feedstock, minimizing sulfur dioxide emissions during combustion. The combined findings strongly position Moringa oleifera leaves as a promising and sustainable candidate for bioenergy production, contributing to the ongoing global efforts for cleaner and more environmentally friendly energy solutions.

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