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Oil Palm Empty Fruit Bunch (EFB) Pellet and Rice Husk Pellet Biomass Fuel in Malaysia: A Comparative Investigation of Moisture, Dry Ash, and Oil Content

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Abstract

In a world heavily reliant on fossil fuels, accounting for a staggering 80% of total energy consumption, the impending exhaustion of these finite resources within the next half-century looms as a dire global crisis. As a response to this impending challenge, biomass energy is emerging as a powerful alternative, harkening back to one of humanity's oldest sources of fuel. Amid this transition, Malaysia, a nation grappling with surging energy demands, holds significant promise in harnessing the latent energy within its abundant agricultural waste, primarily derived from the palm oil (Elaeis guineensis) industry and the extensive cultivation of paddy crops (Oryza sativa L). This study embarks on a critical examination of the potential that agricultural waste, chiefly composed of oil palm empty fruit bunch (EFB) and paddy rice husk (RH), holds in the form of biomass pellets, offering an environmentally friendly and sustainable energy solution. The primary focus of this research is to conduct a comprehensive comparative analysis between EFB and RH pellets, meticulously investigating key parameters such as moisture content, dry ash content, oil content, and ignition time. These parameters were scrutinized to discern which of the two pellet types exhibits greater potential as a viable source of biomass fuel within the Malaysian context. The results indicated that EFB pellets demonstrated superiority in terms of lower moisture content and faster ignition time, while RH pellets exhibited lower dry ash content and sustained combustion.

Keywords: Renewable Energy, Agricultural Waste, EFB, Paddy Rice Husk, Pellet.

1. Introduction

Biomass fuels have long been recognized as a vital option for sustainable energy production, with their potential quickly becoming a mainstream discussion in the renewable energy sector (Al-Suhaibani et al., 2021; Kaniapan et al., 2021; Seleiman et al., 2013; Yadav et al., 2019). Two such biomass fuels under considerable emphasis are Oil Palm Empty Fruit Bunch (EFB) pellets and rice husk pellets, particularly in areas dense in biomass materials like Malaysia (Hansen & Ockwell, 2014).

The EFB pellet is a nascent product derived from oil palm residue, one of the major by-products of the vast palm oil industry thriving in Malaysia (Hansen & Ockwell, 2014; Pusparizkita et al., 2022). On the other hand, rice husk pellets are developed from rice husks, a major waste product of rice processing industries (Moraes et al., 2014). Both of these renewable fuel sources, owing to their parent industries' abundance, offer a significant opportunity for large-scale, environment-friendly, and sustainable energy production (Lin et al., 2013).

However, amid the promises, factors often overlooked in the biomass debate are the moisture content, dry ash content, and oil content of these fuels (Oasmaa et al., 2003). Moisture content affects the calorific value of the fuel, with higher moisture leading to a reduction in energy output. Dry ash content, in contrast, affects the efficiency of combustion and emission characteristics, while oil content can contribute to the energy value of the fuel (Williams et al., 2016). These factors ultimately play a significant role in fuel efficiency and environmental impact, reinforcing the need for a comprehensive examination (Rashidi et al., 2022; Shafie et al., 2011).

In light of this, the current study aims to delve deeper into the characteristics of EFB pellets and rice husk pellets as potential alternative energy sources. The objective is to conduct an intensive comparison of these two biomass fuels, gauging their suitability and performance in relation to their moisture content, dry ash content, and oil content. This examination would pave an informed path towards a sustainable energy future for Malaysia and provide valuable insight into the production and utilization of these fuels. This study also aims at identifying potential areas for improvement within these fuel sources and suggesting future research directions. Herein, a rigorous laboratory examination and comparison of EFB pellet and Rice Husk pellet will be undertaken to determine the more advantageous biomass fuel for Malaysia.

2. Materials and Method

2.1 Moisture, Dry Ash, and Oil Content Testing

Preparation for Moisture Content Testing

Testing the moisture content of particle biomass fuel is essential for determining its quality and performance. A pellet's high moisture content can result in decreased combustion efficiency, increased emissions, and potential storage and transportation issues. Typically expressed as a percentage, the moisture content of a sample is the mass ratio of pore water to solids. Its moisture content has a significant impact on the soil's mechanical qualities. Using the oven dry method, water content can be determined. The moisture content of the sample can be estimated by subtracting the sample's weight before and after drying (Reeb & Milota, n.d.). The oven-drying method is the most widely accepted technique for determining moisture content in solid biofuels, as described in ISO 18134-1:2015 "Solid biofuels — Determination of moisture content — Oven dry method — Part 1: Total moisture — Reference method" (ISO, 2015)

The moisture content (MC) of both EFB pellets and rice husk pellets was determined using the oven-dry method. Ten pieces of 100 ml crucibles were prepared and labelled according to their respective masses. Both EFB pellets and rice husk pellets were separated into five mass variations: 5g, 10g, 15g, 20g, and 25g. The empty mass of each crucible was measured using an electronic balance (M1). EFB pellets and rice husk pellets of varied masses were then placed into each labelled crucible, and the mass of each crucible was measured (M2).

Figure 1 The pellet placed into oven for oven drying phase.

The samples were then placed in an oven at 100 to 110 degrees Celsius for six hours for the dry oven process. After the dry oven process was complete, all samples were transferred to a desiccator for cooling until they reached room temperature. The samples' weight was then measured using an electronic balance (M3). This procedure was repeated until there were three replicates for each sample mass. The replication must be performed to prevent any data gathering errors. The moisture content of the sample was estimated using the equation 1.

$$Moisture\ content, MC\ \% = (M\_2 - M\_3)/(M\_3 - M\_1\ ) \times 100 \qquad \text{Eqn. 1}$$

where

- M_1=Mass empty crucible
- M_2=Mass of crucible with sample before dry oven
- M_3=Mass of the crucible with sample after oven dry

Preparation for Dry Ash Content Testing

The concept of dry ash is based on removing organic material and then assessing how much inorganic material remains. The determination of dry ash content in biomass fuel pellets is based on the procedure described in ISO 18122:2015 "Solid biofuels — Determination of ash content" (International Organization for Standardization, 2015). The dry ash content of both EFB pellets and rice husk pellets was tested by heating the samples in two stages: first, it were fully charred to remove any leftover water, and then it were reduced to ashes at 550°C in a muffle furnace (Capablo et al., 2009). The dry ash testing began by using the same sample collected from the moisture content testing. The mass of each EFB and rice husk pellet was determined using an electronic balance and converted to pre-ignition mass (M_1). The samples were placed in the muffle furnace at 300°C for one hour and then heated to 550°C for eight hours. The samples were allowed to cool after the burning process, and the post-ignition mass (M_2) was measured using an electronic balance. This procedure was repeated until there were three replicates for each sample mass. The replication must be performed to prevent any data gathering errors. The dry ash content of the sample was calculated using the equation 2.

$$Dry\ ash\ contents, AC\ \% = (M\_2 - M\_1)/M\_1\ \times 100 \qquad \text{Eqn. 2}$$

where
M_1= • Mass pre-ignition of sample
M_2= • Mass post-ignition of sample

Figure 2 The sample were placed into the muffle furnace for burning process to collect the dry ash remained.

Preparation for Oil Extraction Testing

The oil content of EFB pellets and rice husk pellets was extracted using a Soxhlet apparatus and hexane. The samples were weighed at 5g, 10g, 15g, 20g, and 25g. Ten round-bottom flasks were weighed using an electronic balance (M_1), and a small amount of dry sample was placed in a thimble. The thimble was then placed in a Soxhlet flask, which was topped with a condenser with flowing water to capture the evaporated hexane. The round-bottom flask was filled with 180ml of hexane solution and placed on a heating mantle. After the hexane solution in the thimble exceeded the overflow level, a siphon returned the solution to the distillation flask. The hexane and oil mixture in the round-bottom flask were then heated for four hours at 90 to 100 degrees Celsius with 40 percent wind. After the hexane had evaporated completely, the sample oils remained in the flask, and the round-bottom flasks were placed in the desiccator to cool to ambient temperature. The final measurement of each flask was obtained using an electronic balance (M_2), and the oil content of the sample was calculated using the following formula:

$$Oil\ Content, \% = ((M\_2 - M\_1\ ))/(Sample\ Mass) \times 100 \qquad \text{Eqn. 3}$$

Where;
M_1= • •Mass empty round bottom flask
M_2= • •Mass round bottom flask that content oil

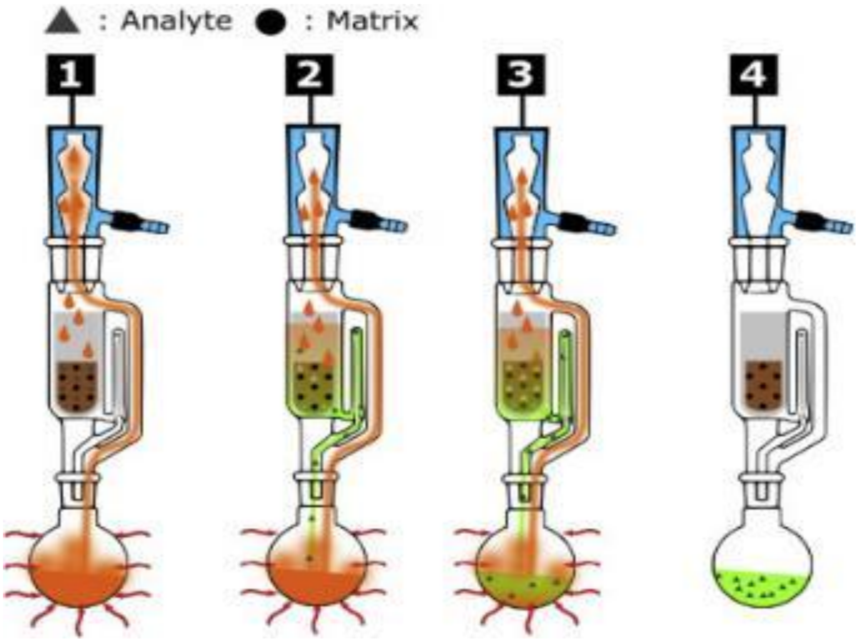

Figure 3 The illustration of oil extraction process by using Soxhlet (Weggler et al., 2020)

Preparation for Time Taken of the Pellet to Start Burning

The time taken for both EFB pellets and rice husk pellets to catch fire was determined by burning each sample on a Bunsen burner. Each sample was separated into five distinct masses: 5g, 10g, 15g, 20g, and 25g. The pellet was then placed in a bowl-shaped aluminium foil that was formed for each weight. Using a Bunsen burner and a tripod, each sample was burned, and the time required for each pellet sample to begin burning was recorded using a timer. This experiment was conducted in a fume hood to prevent smoke from spreading across the facility. The time intervals were measured in four stages, the first of which was the beginning of the flame on the pellet. The pellet continued to burn until the flame was extinguished, at which point the embers on the pellet were also destroyed. This procedure was repeated until there were three replicates for each sample mass.

Figure 4 The pellet burned on the Bunsen burner

Data Analysis

All data collected from the moisture content, dry ash content, oil content, and time taken for the pellet to start burning were analyzed using descriptive statistics. The mean, standard deviation, and coefficient of variation were calculated for each parameter, and the results were compared between EFB pellets and rice husk pellets. The data were analyzed using Microsoft Excel.

3. Result and Discussions

3.1 Moisture content

The moisture content of biomass fuels, such as EFB and rice husk pellets, impacts their performance significantly. A raised moisture content hampers combustion efficiency as it necessitates excess energy for the evaporation of water before combustion can occur (Nussbaumer, 2003). Moreover, the water dilutes the fuel's energy content, thus reducing its heat value (Sheng & Azevedo, 2005).

Higher moisture levels can also lead to storage-related problems such as microbial growth, clustering, and an increased storage footprint due to higher bulk density (Klass, 1998). An elevated moisture content can spur higher emissions of pollutants like CO, VOC, and PM during combustion (Menon & Rao, 2012).

Concerning the physical properties of the pellet itself, excessive moisture can compromise their structural integrity, making the pellets mushy and susceptible to damage, thus rendering handling operations ineffective (Mani et al., 2006). Thereby, for optimal efficiency and minimised potential problems, maintaining minimal moisture content in biomass fuels like EFB and rice husk pellets is crucial.

3.1.1 EFB pellets

The moisture content in biomass fuels plays a significant role in the effectiveness of their combustion, which is influenced not just by the content itself, but also by the variability among various samples. As shown in Table 1, the moisture content in EFB pellet samples varies between 6.630% and 7.590%. The standard deviation values here (ranging from 0.279

to 0.908) indicate that there is variability within the samples. This variability in moisture content can be attributed to factors such as the moisture content of the raw material, the drying process, and the storage conditions(Demirbas, 2007; Patel, 2012).

Of particular interest is the observation that the 15g samples have the highest average moisture content of 7.590%. This finding suggests a peak in moisture content at this sample weight. It is important to note that a higher moisture content can have a detrimental effect on combustion efficiency. When biomass fuel with high moisture content is burned, a significant amount of energy is required for water evaporation before combustion can occur. This results in reduced combustion efficiency and lower energy output (Nussbaumer, 2003).

On the other hand, the minimum moisture content (6.630%) was identified in the 25g samples, illustrating that heavier EFB pellet samples might carry less moisture, yielding potentially higher combustion efficiency. Yet, both the high and low moisture contents recorded fall within acceptable ranges for use as a biomass fuel, according to Menon and Rao (2012).

Table 1: Moisture content mean for EFB pallets.

Samples (g)	Mean	N	Std. Deviation	Std. Error Mean
5	6.963	3	0.346	0.200
10	6.903	3	0.542	0.313
15	7.590	3	0.464	0.268
20	6.807	3	0.908	0.524
25	6.630	3	0.279	0.161

3.1.2 Rice husk pellets

In contrast to EFB pellets, rice husk pellets exhibit a higher moisture content overall, as illustrated in Table 2. The moisture content in these samples ranges from 8.420% to 8.820%. Similar to EFB pellets, the moisture content in rice husk pellets also plays a key role in efficient combustion processes.

It's important to highlight that these rice husk pellets maintain a relatively higher average moisture content even in the larger 25g sample (8.820%), whereas the EFB pellets had a declining trend of moisture content with increased sample weight. The consistency in high moisture content may indicate a potentially lower combustion efficiency (Nussbaumer, 2003), although still within acceptable ranges for biomass fuels (Menon & Rao, 2012). The standard deviation values, ranging from 0.072 for the 25g sample to 0.682 for the 15g sample, suggest there is some variability within each set of samples as well. This could be due to differences in the processing or handling of rice husk pellets.

Table 2: Moisture content mean for Rice Husk pallets.

Samples (g)	Mean	N	Std. Deviation	Std. Error Mean
5	8.420	3	0.644	0.372
10	8.547	3	0.307	0.177
15	8.690	3	0.682	0.394
20	8.617	3	0.390	0.225

25	8.820	3	0.072	0.042

3.1.3 Comparison of moisture content between EFB and rice husk pellets

In this comparative study between EFB and Rice Husk (RH) pellets, two distinct biomass pellet samples were evaluated across five different masses: 5g, 10g, 15g, 20g, and 25g. A total of 10 sample sets were examined, each featuring three replicates - amounting to a total of 30 measurements. The rationale behind employing replicates for each sample lies in enhancing the precision of the collected data, and minimizing potential errors that may arise during the data gathering process. This approach ensures a more robust validity in the evaluation, providing a dependable foundation for analyzing the moisture content comparisons between EFB and RH pellets.

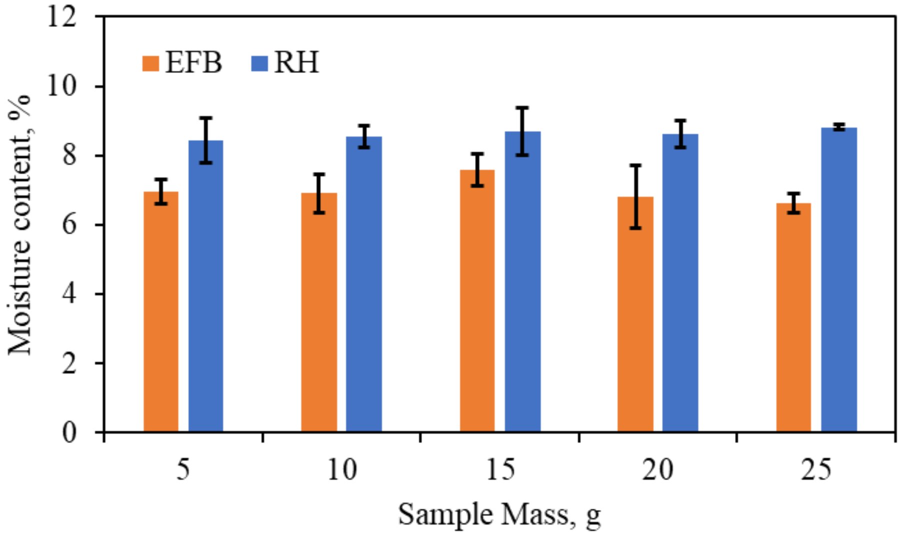

Figure 5 The result of the comparison on mean moisture content

Figure 5 showcases that the moisture content in Oil Palm Empty Fruit Bunch (EFB) pellets is lesser than that in Rice Husk (RH) pellets. This is consistent across all tested EFB pellet samples when compared to RH pellet samples. While the difference in moisture content isn't dramatic, it is pivotal in enhancing the combustion efficiency of EFB pellets. The profound impact of moisture content on the burning properties of biomass used as fuel is well-documented (Demirhan & Özbek, 2009). It can diminish flame temperature and boiler efficiency, leading to incomplete fuel combustion and other complications.

According to Jackson et al. (2016), the preferred moisture range for producing pellets is 10-15%. This range ensures optimal combustion efficiency and prevents operational issues such as incomplete fuel combustion, slagging, and fouling. It is important to note that both EFB and RH pellets fall within this preferred moisture range, making them suitable options for long-term storage(Saeed et al., 2021).

The literature also highlights the importance of moisture content in biomass fuels. Demirbas (2007) explains that higher moisture content in a fuel decreases its higher heating value (HHV) and can lead to decreased boiler efficiency. On the other hand, lower moisture content is desirable for biomass fuels as it improves their heating value and combustion efficiency. Saeed et al. (2021) emphasize that the moisture content of rice husk blends affects the heating value and combustion properties of briquettes made from them. They found that a moisture content of 14% resulted in the highest calorific value and desirable morphology for rice husk briquettes.

In conclusion, the comparative study between EFB and RH pellets reveals that EFB pellets have lower moisture content than RH pellets. This difference in moisture content is crucial for enhancing the combustion efficiency of EFB pellets. Both EFB and RH pellets fall within the preferred moisture range for biomass fuels, ensuring their suitability for long-term storage and use as a renewable energy source. The literature supports the importance of moisture content in biomass fuels and its impact on combustion efficiency and heating value. Further research can explore the specific effects of moisture content on the combustion properties of EFB and RH pellets to optimize their utilization in biomass energy production.

3.2 Dry Ash Content

The percentage of dry ash in biomass fuels, such as EFB and rice husk pellets, impacts their performance in multiple ways. A higher ash content reduces the efficiency of combustion and can contribute to incomplete combustion. Furthermore, ashes with a higher percentage of particulate matter and potentially hazardous pollutants increase emissions. In addition, a higher ash content necessitates proper disposal and can contribute to higher costs and management difficulties. High ash content can cause fouling, slagging, and corrosion in boilers, decreasing their efficacy and increasing their maintenance requirements. Thus, to maximise performance, it is essential to minimise the dry ash content of biomass fuel via correct fuel selection and quality control measures. This enhances combustion efficiency, decreases emissions, and reduces operational difficulties.

3.2.1 Comparison of dry ash content between EFB and rice husk pellets

In the study of biomass fuels, understanding the ash content is of profound importance as it directly influences the energy output, or the calorific value of the fuel. High ash content often indicates a lower energy output or lower combustion efficiency. This understanding is particularly relevant when different biomass fuels, like Oil Palm Empty Fruit Bunch (EFB) and Rice Husk (RH) pellets, are compared. To that end, a comprehensive analysis of their ash contents has been undertaken (van Loo & Koppejan, 2012).

Table 2 presents this comparison, focusing on the mean dry ash content for EFB and RH pellets at varied sample weights (5g, 10g, 15g, 20g). Each of these weights represents the 'Sample (g)' column. Subsequent columns - 'Mean', 'N', 'Std. Deviation' and 'Std. Error Mean' - shed light on the mean ash content, number of measurements for each sample, variability in the readings, and the standard deviation of the sampling distribution, in sequence.

The findings reiterate that as the sample size increases, the ash content exhibits a corresponding rise for both EFB and RH. It is noteworthy, however, that the EFB pellets consistently display lower mean ash content across all samples, thus suggesting a higher energy efficiency relative to the RH pellets(Gallastegui et al., 2015).

Table 2 Comparison of dry ash content for EFB and RH pellets

Sample (g)		Mean	N	Std. Deviation	Std. Error Mean
5	EFB	6.2733	3	.65256	.37676
	RH	7.2200	3	.27514	.15885
10	EFB	9.6333	3	1.24797	.72052
	RH	11.1967	3	1.75643	1.01407

15	EFB	11.6200	3	.75319	.43486
	RH	15.7133	3	1.29616	.74834
20	EFB	13.4767	3	1.27226	.73454
	RH	20.3833	3	1.04333	.60237
25	EFB	15.8600	3	.62857	.36290
	RH	22.4000	3	.87710	.50639

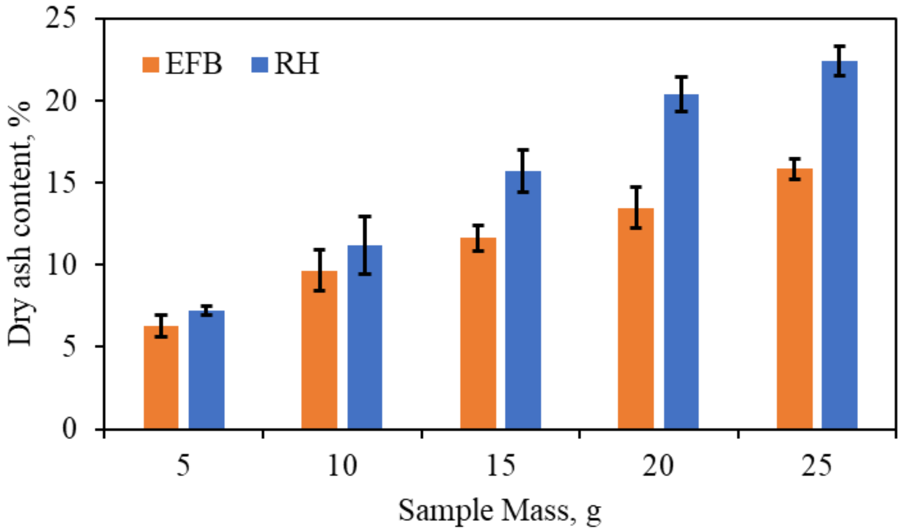

Figure 6 Result of the comparison on mean dry ash content.

Figure 6 graphically illustrates a lower ash content in Oil Palm Empty Fruit Bunch (EFB) pellets as compared to Rice Husk (RH) pellets. Predominantly, EFB pellets yield less residual ash, making them more efficient in terms of combustion, when compared to RH pellets. Assessing ash production is fundamental when evaluating steam coals or industrial furnace coals, as a high ash yield can adversely affect the heating calorific value, detracting from the energy derived during combustion (University of Kentucky, 2023). Increased ash implies a lower calorific value due to the inverse relationship between the two (Suroto and Triyono, 2017).

The standards in utility contracts typically require that the ash content in steam coals used for power generation be less than 10% and, post air-drying, most steam coals used for electricity generation should not exceed an ash content of 20% (University of Kentucky, 2023). Being the unburnable coal component, the ash content indicates the amount of waste post-combustion. In light of this, we can infer that EFB pellets possess a comparatively higher calorific value given their lower ash content, enhancing their suitability over RH pellets as a bioenergy source.

3.3 Oil Content

The efficiency of biomass fuels like EFB and rice husk pellets is impacted by their oil content in a number of ways. Firstly, higher oil content reduces the efficiency of combustion and can contribute to incomplete combustion. Biomass with a high oil content can increase ash and deposits during combustion, resulting in contamination and increased maintenance needs. Furthermore, higher oil content results in greater CO, VOC, and PM emissions during combustion. During storage and handling, biomass fuel with a high hydrocarbon content can degrade and emit odours. In addition, a high oil content can reduce the durability of biomass pellets, leading to increased breakage and decreased efficacy in handling. Thus, to maximise performance, it is essential to minimise the oil content of biomass fuel through appropriate processing and quality control. This improves combustion efficiency, decreases emissions, reduces ash and deposits, increases pellet storage stability, and preserves pellet integrity.

3.3.1 Comparison of oil content between EFB and rice husk pellets

The selection of biomass fuel depends significantly on its oil content. High oil content in biomass typically correlates with higher energy density, emphasizing the relevance of comparative analyses in determining the suitable biomass fuel choice (Liu et al., 2012). Table 3 elucidates the comparison of oil content between Oil Palm Empty Fruit Bunch (EFB) and Rice Husk (RH) pellets. The quantification is based upon different sample sizes, varying from 5g to 25g. The columns 'Mean', 'N', 'Std. Deviation', and 'Std. Error Mean' represent the mean oil content, number of measurements taken, variability of the data from the mean, and the dispersion of the sampling distribution, respectively.

Table 3 The result of comparison on oil content for EFB and rice husk pellets

Sample		Mean	N	Std. Deviation	Std. Error Mean
5g	EFB	1.0133	3	.25166	.14530
	RH	0.7067	3	.20817	.12019
10g	EFB	1.2867	3	.13650	.07881
	RH	0.6267	3	.13013	.07513
15g	EFB	1.5933	3	.06658	.03844
	RH	0.6933	3	.24947	.14403
20g	EFB	1.9400	3	.09644	.05568
	RH	0.6867	3	.05508	.03180
25g	EFB	2.2033	3	.14468	.08353
	RH	0.7967	3	.08327	.04807

Across every sample size, EFB pellets exhibit significantly higher oil content compared with RH pellets. The trend suggests that the biomass' oil content increases as the size of the EFB sample increases. This high oil content in EFB pellets would typically translate into higher energy density, making it a more efficient biomass fuel source according to the studies by Liu et al., (2012) and Mani et al. (2006). Considering the patterns identified in this data, EFB pellets' greater oil content signifies them as potentially more efficient biomass fuel compared to RH pellets.

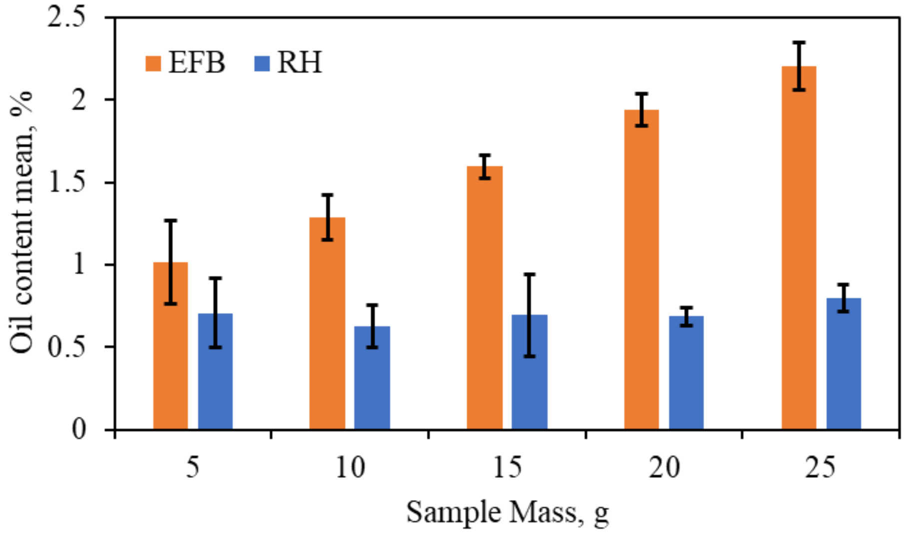

Figure 7 The result of the comparison on mean oil content

The oil content of EFB pellets was compared to RH pellets in Table 3. Figure 7 demonstrates that the EFB pellet sample contained more oil than the RH pellet sample. All of the EFB pellet samples exhibit a higher oil content than the RH pellet samples. It appears that the Oil Palm Empty Fruit Bunch (EFB) pellets consistently have a higher oil content than the Rice Husk (RH) pellets, regardless of the sample size. Starting from a 5g sample to 25g sample, the oil content of EFB pellets increases from 1.0133g with a standard deviation of 0.25166, to 2.2033g with a standard deviation of 0.14468. This indicates that as the size of the EFB pellet sample increases, the oil content proportionally increases as well and exhibits less variability. When the oil content exceeded 7.5%, the pellets burned for a shorter period of time. Since the quantity of oil grew, the pellets' quality declined. When the oil concentration in pellets reached 7.5%, their durability decreased (Briggs et al., 1999). Thus, RH pellets exhibit greater durability compared to the EFB pellets because of lower oil content.

In contrast, the oil content of RH pellets seem to remain relatively steady, regardless of sample size. It ranged from 0.7067g to 0.7967g. While there is a slight increase in oil content as the sample size grows, the increase is not proportional like it is in EFB pellets. Furthermore, the oil content and percentage of oil content also influence the increased calorific value of the biofuel. EFB pellets that contain less than 7.5% oil are nevertheless an effective biofuel for industrial use. In summary, EFB pellets have a noticeably higher oil content compared to RH pellets. This feature suggests that EFB pellets may provide a higher energy density than RH pellets, given that higher oil content can signify greater energy per unit of mass. This could make EFB pellets a more efficient form of biomass fuel, according to the oil content alone. Other factors, such as moisture and dry ash content, would also need to be considered for a comprehensive comparison.

3.4 Time Taken for Pellets to Start Burning

3.4 Ignition Time for EFB and RH Pellets

The functionality of EFB and RH pellets as biomass fuel is significantly impacted by their ignition time. Higher combustion efficiency, which is crucial for optimal energy output and better efficiency, is adversely affected by prolonged ignition periods. Conversely, shorter ignition periods can enhance the combustion efficiency. The ignition duration also influences

the start-up time. Longer ignition periods result in a subsequent delay in the generation of valuable heat or power, negatively impacting the system's promptness. These varying ignition periods can also destabilise the combustion process, resulting in irregular performance.
During the start-up phase, the emission of pollutants such as CO, VOCs and PM is heightened due to lengthened ignition periods. Mitigating ignition times can potentially decrease these detrimental emissions. Prolonged ignition periods additionally result in mounting operational costs. This is due to the increase in fuel consumption and extended start-up times that accompany longer ignition periods. Shorter ignition durations, hence, play an essential role in maintaining operation costs. To optimise the use of biomass fuel, shorter ignition durations are favoured. However, achieving this requires precise pellet properties, innovative system design, effective preheating, and well-adapted operating conditions.

3.4.1 Comparison of time taken for pellets to start burning between EFB and rice husk pellets.

Biomass pellet ignition time is a crucial criteria in choosing a suitable biofuel, where faster ignition indicates higher combustion efficiency (Basu, 2010). Table 4 presents a comparison of the time required for Oil Palm Empty Fruit Bunch (EFB) and Rice Husk (RH) pellets to initiate combustion. The table investigates various pellet masses (5g, 10g, 15g, 20g, and 25g), with each mass considered as a separate sample. For each sample mass, three replicate measurements were taken to enhance data accuracy and minimize collection errors.
Table 4 Shows the result of comparison time taken pellet start burning mean.

Sample		Mean	N	Std. Deviation	Std. Error Mean
5g	EFB	.9000	3	.34641	.20000
	RH	1.2667	3	.15275	.08819
10g	EFB	1.0333	3	.46458	.26822
	RH	1.3167	3	.14434	.08333
15g	EFB	1.3333	3	.16073	.09280
	RH	1.4667	3	.10408	.06009
20g	EFB	1.3000	3	.10000	.05774
	RH	1.7333	3	.44814	.25874
25g	EFB	1.3833	3	.11547	.06667
	RH	2.2667	3	.25166	.14530

Analysis indicates an increase in ignition time as sample mass raised for both EFB and RH pellets. However, EFB pellets consistently demonstrated a shorter ignition time compared to RH pellets across all sample masses. This observation suggests that EFB pellets may exhibit a higher combustion efficiency due to their faster ignition time, thus establishing them as a potentially more efficient biomass fuel (Tumuluru et al., 2011). Hence, considering combustion efficiency, EFB pellets may provide a more advantageous biofuel alternative than RH pellets due to their shorter ignition time under the evaluated conditions.

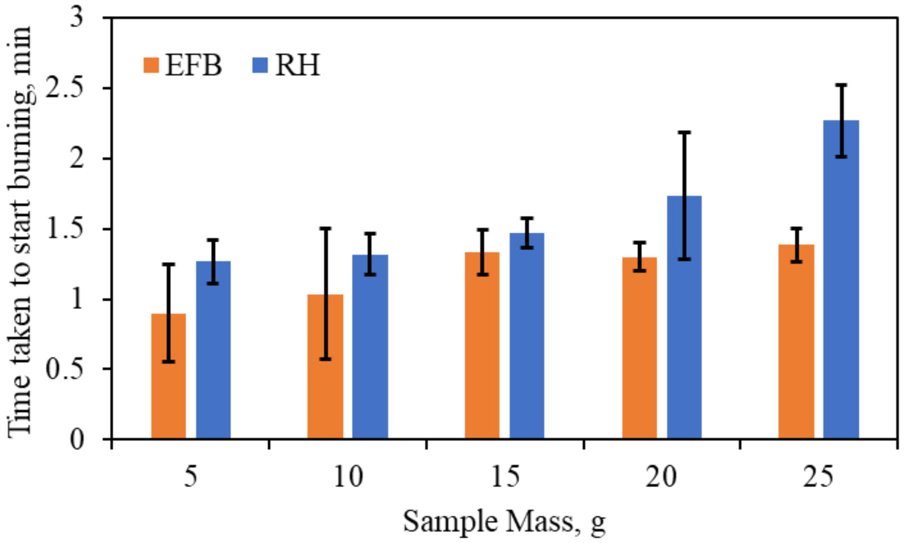

Figure 8 The result of the comparison on mean time taken for pellet start burning.

Figure 8 reveals a trend wherein the ignition time for Oil Palm Empty Fruit Bunch (EFB) pellet samples is consistently shorter than that for Rice Husk (RH) pellet samples. Interestingly, the moisture content within the pellets plays a pivotal role in influencing the ignition time. Higher moisture content requires a greater amount of thermal energy to initiate combustion, thus lengthening ignition time (Bazarov et al., 2022)

Relative to ignition efficiency, EFB pellets demonstrate superior performance by necessitating a shorter ignition period. One potential explanation for this could be rooted in the oil content of the pellets, a critical determinant of ignition time (Mansaray & Ghaly, 1999). Oil-rich biomass fuels often require shorter ignition times due to the higher energy content within oil (Al Naggar et al., 2017)

3.5 Relationship between biomass fuel combustion and moisture content, oil content, manual flash point, and dry ash content.

To thoroughly comprehend the impact of biomass pellet characteristics on combustion performance, Table 5 elucidates the relationship between combustion and variables including moisture content, oil content, flash point, and dry ash content. Table 5 presents a comparative view of mean data derived from the combustion tests of 25g Oil Palm Empty Fruit Bunch (EFB) pellets and 25g Rice Husk (RH) pellets, specifically focusing on two key phases: flame and ember. The table also presents the standard deviation and the standard error mean to depict the dispersion and the precision of the gathered data, respectively.

Table 5: Comparison of mean data during combustion of pellet

Sample		Mean	N	Std. Deviation	Std. Error Mean
FLAME	25g EFB	17.0167	3	.58595	.33830
	25g RH	14.1000	3	.56789	.32787
EMBER	25g EFB	9.2000	3	.87607	.50580
	25g RH	6.5500	3	.61441	.35473

For the flame phase, the mean value for EFB pellets was recorded at 17.0167 while RH pellets exhibited a mean value of 14.1000. The standard deviation, depicting the data spread around the mean, was higher in EFB pellets (.58595) as compared to RH pellets (.56789). In the ember phase, both types of pellets exhibited a decrease in mean values, with the EFB pellets registering at 9.2000 and the RH pellets at 6.5500. The standard deviation for EFB pellets was calculated as .87607, slightly exceeding the value calculated for RH pellets (.61441). From these findings, EFB pellets demonstrate superior performance both in the flame and ember phases, exhibiting higher mean values, indicating a longer duration of combustion phases which can lead to better fuel performance (Demirbas, 2004).

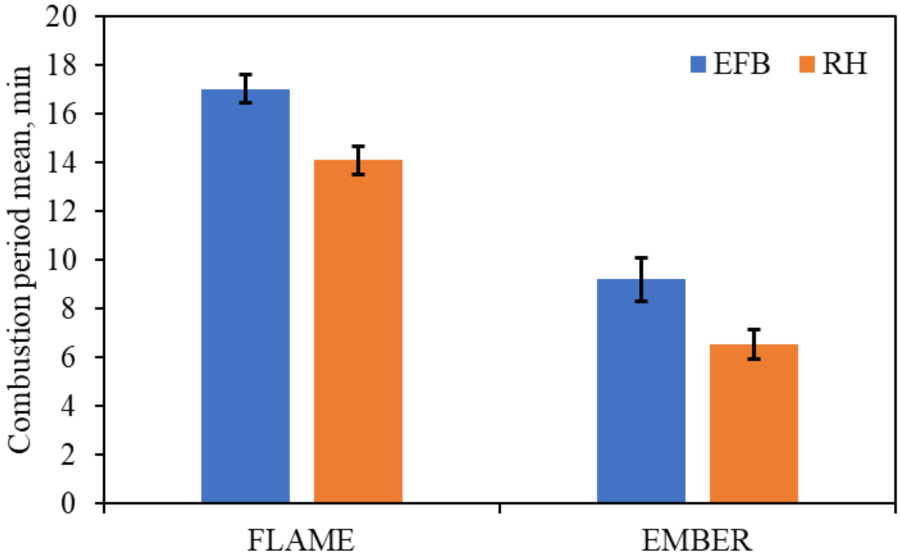

Figure 9 Comparison on mean period of the pellet

Figure 9 demonstrates that the moisture content, oil content, and also dry ash content had a strong association with pellet quality. During the combustion of these pellets, EFB required less time to ignite than rice husk pellet, as indicated by the results of the oven dry test method. In addition, during pellet combustion, the EFB pellet's flame had a longer duration than the rice husk pellet's flame. The pellet's oil content affected the duration of the flame during burning. The oil content test that had been undertaken before to this resulted in this conclusion. In addition, even after the fire has been extinguished, the pellets still contain embers, and the pellets will continue to burn until they are completely reduced to ash. In addition, after the pellets were burned, the EFB pellet produced less ash than the rice husk pellet did. The quantity of ashes that remained after pellet combustion was complete also contributed to the pellet's high grade. This was attributable to the fact that the EFB pellets had entirely burned as a result of their lower moisture content and higher oil content.

3.6 Overall Comparison of EFB and Rice Husk Pellets

The overall comparative analysis between Oil Palm Empty Fruit Bunch (EFB) pellets and Rice Husk (RH) pellets provides notable insights into the potential utilization of these biomass fuels. From the moisture perspective, higher moisture content can increase the energy required for combustion, subsequently prolonging the ignition time. Both EFB and RH pellets have demonstrated varying moisture contents, influencing their individual ignition times and combustion efficiencies.

On the matter of oil content, EFB pellets emerge as superior due to their inherent oily nature. High oil content often corresponds with quicker ignition and combustion times, due to the higher energy content within oil. It can be inferred that the oil content within EFB pellets has likely enhanced their ignition efficiency compared to RH pellets.

Investigating their combustive performance, EFB pellets outperformed RH pellets in both the flame and ember stages, signifying a prolonged combustion phase, as evidenced by the data presented in Table 5. This extended combustion duration suggests better fuel efficiency, a desirable characteristic in the context of biomass fuels.

In summary, due to their superior ignition efficiency and prolonged combustion phases, EFB pellets present a more promising biomass fuel compared to RH pellets. However, the suitability of these fuels can also be dictated by other factors such as environmental impacts, economic considerations, and regional accessibility to the particular type of biomass (Demirbas, 2004).

4. Implications of the findings

a. Potential benefits

The implications of the findings offer noteworthy benefits in the context of biomass utilization, particularly the use of Oil Palm Empty Fruit Bunch (EFB) and Rice Husk (RH) pellets. One of the main potential benefits is increased energy efficiency. EFB pellets have exhibited a prolonged combustion phase in comparison to RH pellets, signaling superior energy output. This capacity indicates a broader range of use, particularly in power generation and heating applications where improved energy efficiency is advantageous.

This study also underlines the environmental significance of biomass fuels. As renewable energy sources, EFB and RH pellets support the reduction of greenhouse gas emissions, offering an environmentally friendly alternative to traditional fossil fuels. Thirdly, the study aids in waste management, demonstrating how agricultural by-products such as EFB and RH can be effectively converted into valuable resources. This conversion reduces waste while also creating additional economic value in the agricultural industry.

The economic viability of these biomass fuels also surfaces as a potential benefit. EFB and RH pellets, given their relative abundance and economical production cost, propose an economically sustainable solution for energy production. Finally, the findings contribute to the diversification of energy sources. By identifying and establishing the potential of new types of biomass fuels, we enhance energy security and independence, reducing reliance on conventional fossil fuels.

b. Drawbacks of using each type of biomass fuel

Despite the potential benefits, there are also drawbacks associated with the use of both Oil Palm Empty Fruit Bunch (EFB) and Rice Husk (RH) pellets as biomass fuels. For EFB pellets, their high moisture and oil content, as revealed in our investigation, can affect combustion efficiency. A high amount of moisture in the fuel can increase the energy required for drying the fuel before combustion while elevated oil content can cause difficulties in pelletizing and increase the risk of spontaneous combustion during storage.

With respect to RH pellets, despite their lower moisture content, their high ash content presents a significant challenge. High ash content can lead to slagging and fouling problems during combustion, which affect the boiler efficiency and maintenance requirements. The ash can increase the frequency of cleaning cycles and may result in operational downtime. Moreover, the inherent characteristic of biomass fuels, including EFB and RH pellets, such as low energy density and bulkiness, pose logistical challenges. They occupy a large space during storage and transport, increasing the cost associated with these operations.

Lastly, although these biomass sources are classified as renewable, their availability is seasonally determined by the crop cycles. This means there could be periods of shortage, disrupting energy production and creating dependent on crop seasons.

5. Suggestions for future research

In view of the findings and challenges encountered in this study, future research could focus on several facets to further streamline the use of biomass fuels. Further investigation is warranted on methods to reduce the moisture and oil content in EFB pellets. Techniques such as pre-treatment or drying processes could be explored to enhance their combustion efficiency. Additionally, it would also be of interest to investigate safe techniques for storing and transporting EFB pellets to overcome the tendency for spontaneous combustion.

As for RH pellets, methods to reduce ash content should be a primary focus in future studies. Identifying novel ash reduction techniques or improving ash utilization could mitigate concerns about slagging and fouling. Advancements in pelletization techniques for both EFB and RH pellets could be beneficial to improve the overall fuel quality and combustion efficiency. Research should also delve into economic analysis of biomass utilization and development of strategies to make its use more economically viable. This could involve exploring cost-effective transport and storage options, assessing the impact of quality improvement techniques on the cost, and identifying markets for biomass fuels. Finally, it would be advantageous to examine the potential for aligning the production and use of biomass fuels with agricultural activities to create a sustainable supply chain, not disrupted by crop seasons.

To overcome the constraint of sustaining the agricultural industry, such as oil palm and paddy crops, it is essential to implement effective techniques and management. Renewable energy sources are essential to the reliability of electricity and nonrenewable energy sources, such as diesel, in the contemporary industrial sector. Using alternate energy sources reduces dependency on finite fossil fuels. The majority of the energy that we consumed came from fossil fuels, almost 80%. It is estimated that the reserves of nonrenewable energy that we currently have will last for fewer than fifty years. To prevent an infinite amount of agricultural waste from damaging the environment, the government should commercialise the potential of these biomass fuels as an alternative and replacement for the future depletion of existing energy resources.

Aside from this, there is a constraint that could be improved by additional inquiry. Thus, there are several proposals that can be implemented to advance renewable energy growth. Analyzing the calorific value of these pellets, for instance, is essential for determining which of these biomass fuels is the most efficient and appropriate for future industrial application. As a green energy source for the future, EFB pellet has more advantages than rice husk pellet. But, rice husk pellets can also be utilised as a replacement for EFB pellets because the gap between these two fuels is not too significant.

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