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RESEARCH ARTICLE

Innovative Biomass Blending: Improving Oil Palm Trunk Pellet Characteristics with *Acacia Mangium* Wood for Bioenergy Production

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ABSTRACT - The increasing consumption of renewable resources is driven by the global demand for energy, rising fossil fuel prices, and the depletion of petroleum. Using biomass to substitute fossil fuels lowers their environmental impacts. Currently, pellet production from non-woody biomass is on the rise, emphasizing the sustainable use of these bioenergy sources due to their quality. This study investigates the potential of OPT, particularly abundant in Sarawak, for pellet utilization. The pellet properties from OPT were improved by blending with fast-growing species such as *A. mangium* at different blending ratios, focusing on physical, chemical, and energy properties. Both types of biomass in fibre form were processed using a pelletizing machine. The pellets produced were analyzed to evaluate the moisture content (MC), bulk density, ash content, and calorific value (CV). Blending biomass pellets decreased the ash content from 2.1 to 2.0%, while the CV increased from 17.4 to 18.4 MJ/kg when 30% OPT was blended with 70% *A. mangium*. The results obtained meet commercial pellets standards, indicating that blended biomass pellets offer improved quality and high potential as bioenergy products.

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1. INTRODUCTION

The decrease in fossil fuels as an important energy source and the enormous environmental impact on their consumption have led to great concern regarding renewable energy sources [1,2]. Biomass materials are one of renewable energy sources. However, the direct use of this biomass for bioenergy applications has generated several problems, such as uneven shape, high moisture content, and low bulk density, which cause difficulties in handling, transport, and storage. One solution to these issues is through the densification of these biomass materials, such as the pelletizing process and the standardization of its procedure to produce high-quality pellets that create a consistent and easy-to-use solid biofuel [2,3]. The development of renewable energy solutions, including biomass pellets, is closely aligned with the Sustainable Development Goals (SDGs) set forth by the United Nations [48]. Specifically, SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) are directly relevant to the biomass pellet research, as they emphasize the need for clean energy transitions and the mitigation of climate change [49]. Highlighting the study's contributions to these global sustainability objectives can enhance its significance and impact.

Biomass is one of the most attractive alternative energy resources in the world because it is renewable, inexpensive, readily available, and can be converted into various forms of bioenergy products [4,5]. There are many types of biomass such as woody biomass, energy crops, agricultural residues, non-woody biomass and others [6] that can be used as a feedstock for the bioenergy production. In recent years, many studies have been conducted to produce biomass pellets from wood, agricultural residues, and forestry residues. Biomass in the form of pellets produces a more cost-effective bioenergy product that can be use directly for energy production [2,5]. Moreover, biomass pellets are among the fastest-growing renewable bioenergy sources in the world since the production process is direct and low-cost compared to other types of bioenergy products, such as charcoal and briquettes, which require high energy consumption. In 2019, the global production of biomass pellets was about 38.9 million tons, mostly from woody biomass materials [7]. In 2023, the global wood pellet market was valued at USD 9.58 billion and is anticipated to generate an estimated revenue of USD 14.42 billion by 2032, with a Compound Annual Growth Rate (CAGR) of 4.70% from 2024 to 2032 [8].

Currently, woody biomass is the primary and ideal feedstock for pellet production [9]. A timber wood species like *A. mangium* is one of the major fast-growing species used in plantation forestry programs throughout Asia and the Pacific countries. In 2005, Malaysia has developed the forest plantation programme where *A. mangium* is one of the selected species. Under this programme, about 130,000 hectares of forest plantation was targeted that is expected to produce 26 million cubic meters of timber [10]. Due to its rapid growth and tolerance of very poor soils, *A. mangium* has become increasingly important in efforts to sustain the commercial supply of timber products while reducing pressure on natural forest ecosystems. *A. mangium* plantations are estimated to provide efficient and profitable contributions to the bioenergy products markets [11].

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Considering the increasing demand for wood pellets and the limited supply of woody biomass materials, there has been growing interest in exploring the production of pellets from other sources, such as non-woody biomass [2,12]. Non-woody biomass is the most important alternative feedstock for pellet production, as it is available in large quantities at a low price and can support and maintain a green and circular economy [2,13,14]. The oil palm tree is a non-woody biomass plant in Malaysia, generating a huge amount of oil palm biomass, accounting for about 40 million tons, including trunks, fronds, and empty fruit bunches. About 90% of this oil palm biomass was left at the plantation during felling for replanting, and these felled palm trees are shredded and left in the field for soil regeneration purposes. As a result, this oil palm biomass has high potential to be converted into bioenergy products such as pellets. However, the problem with pellets produced using non-woody biomass, such as oil palm biomass, is that they are of lower quality than woody biomass pellets in terms of bulk density, ash content, and CV [15]. One of the promising solutions to improve pellet properties is by blending woody and non-woody biomass [2,16]. Blending different types of biomass materials to improve the properties of pellets has been conducted in several studies [17]. The effect of mixing wheat at 15 to 60% with turkey breeder was studied, and it showed that the durability of the pellets increased from 32 to 45% and up to 74% [18]. Additionally, pellets produced by blending pine and spruce sawdust with bamboo increased the bulk density from 540 to 600 kg/m^3 and improved the ash content to below 8% [19].

The aim of this study is to enhance the properties of pellets produced from OPT by blending them with *A. mangium* wood at different blending ratios of 30:70; 50:50, and 70:30 to obtain the highest quality pellets compared to commercial pellet standard requirements.

2. METHODS AND MATERIAL

2.1 Oil Palm Trunk (OPT) and A. mangium Samples Preparation

OPT and *A. mangium* were processed into smaller sizes in the form of chips using a chipper machine. After that, both types of chip biomass were further processed into sawdust and dried in an oven until the moisture content (MC) was below 10%. Then, the dried samples were ready to produce pellets.

2.2 Production of Blending Biomass Pellet

Initially, the pure pellets were produced from OPT and *A. mangium*, which will be used as a control to study the effectiveness of blending biomass pellets. The preliminary results of physical, proximate, energy properties, and elementals analyses were obtained and will be used to compare with the blended biomass pellets. Then, OPT and A. mangium were blended together according to the ratios given in Table 1, which where 30:70, 50:50, and 70:30, respectively. After that, blended biomass pellets were produced by compressing the blended samples into a mold according to the required size or dimensions (Figure 1).

Table 1. Mix ratio of OPT and *A. mangium*

Biomass	Percentage of mix ratio (%)				
OPT	0	30	50	70	100
A. mangium	100	70	50	30	0

The pelletization process was carried out at a temperature of 70^{o}C at a compression pressure of 4 tons for a duration of about one (1) hour to produce 1 kg of pellet from 3 kg of raw materials. High pressure applied during the process increased the temperature of the samples, and the lignin content present in the samples acted as a natural binder when the pellets produced cool. The pelletizing machine used automatically cut the pellets to the desired pellet length.

Figure 1. Blending biomass pellet from OPT and *A. mangium*

2.3 Analysis of Blended Biomass Pellets

Characterization of pure pellets and blended biomass pellets produced from OPT blended with *A. mangium* was conducted based on its physical, chemical, and energy properties. For physical properties, the bulk density is an important parameter that needs to be measured. In addition, pellet durability and fine content are also important for characterizing physical properties. For dimensional analysis and durability of pellets, the standard method BS: EN 15210-1: 2009 [20] was used.

For chemical properties, proximate analysis is an important characteristic for determining the quality of the produced pellets. Two (2) important parameters that need to be measured are MC and ash content. The analysis was performed based on standard methods BS EN 15148 [21] and BS EN 14775 [22], respectively. This testing was conducted by heating and combusting the pellets in a furnace at high temperature of up to 900ºC. Additionally, energy properties in terms of CV were also analyzed using the standard method BS EN 14918 [23] and reported in two different units: MJ/kg and kcal/kg. The CV of the produced pellets was measured at constant volume on a dry basis using a bomb calorimeter (LECO Instrument). Meanwhile, the analysis of N and S content was performed using a CHNS analyzer (LECO Instrument Model 628), and an Inductive Couple Plasma Spectrophotometer (ICP-OES, Perkin Elmer, Avio 500) was used to determine the elemental content. Moreover, for chlorine (Cl) content, the test was performed using the standard method ISO 587.

3. RESULTS AND DISCUSSION

3.1 Properties of Pellet Produced from OPT and A. mangium

Initially, the production of pellets was carried out using 100% OPT and *A. mangium* wood to create the baseline study for improving the properties of blended biomass pellets. The properties of the pure pellets produced are shown in Table 2. It was found that pellets produced using woody biomass, specifically *A. mangium*, have better properties compared to non-woody biomass materials (OPT). This finding supports the results reported by Picchio et al. [2] and Tenorio et al. [15]. Furthermore, the differences in pellet properties are influenced by the chemical composition of the biomass, which includes the content of cellulose, hemicellulose and lignin. According to the chemical composition of OPT [24] shown in Table 1, it is less than that of *A. mangium* [25]. This is because woody biomass like *A. mangium* contains a higher lignin content, which provides structural support to plant materials that contribute to the pellet's structural integrity and combustion characteristics. Cellulose, a carbohydrate polymer, has a high cellulose content in woody biomass, when converted into pellets. It can enhance the fuel's CV and combustion efficiency. Additionally, pellets produced from oil palm biomass, such empty fruit bunches (EFB), oil palm frond (OPF), OPT, mesocarp fibres and OPF leaves, do not perform well, showing problems related to durability, bulk density, ash content, and CV [2,5,15]. Moreover, the bulk density of non-woody biomass is lower than that of woody biomass [26]. This statement supports the findings that 100% OPT had a lower bulk density of 550 kg/m^3 compared to *A. mangium* pellets (589 kg/m^3), with a different of 7.1%. Additionally, Muda et al. [42] reported that the CV of OPT ranged from 16.6 to 18.1 MJ/kg, which is in line with the results of this study.

Table 2. Properties of OPT and *A. mangium*

Properties	OPT	A. mangium	Commercial pellet grade 1 [55]
Diameter (mm)	8.2	8.2	6-8
Length (mm)	51.2	33.4	<32
Bulk density (kg/m^3)	550	589	>600
Durability (%)	94.8	97.5	>97.5
Fines (%)	0.16	0.18	<1
MC (%)	6.1	6.2	<10
Ash content (%)	2.2	1.3	<0.7
CV (MJ/kg)	17.4	18.7	>18
CV (kcal/kg)	4146	4475	>4300

3.2 Effect of Blending of OPT and A. mangium on Its Physical Properties

Blending two or more feedstock is one of the promising solutions to improve pellet quality, which is also known as co-pelletization. The general trend is to use woody biomass to enhance the overall quality of pellets produced from non-woody biomass. The high lignin content in woody biomass helps to improve the pellet quality of non-woody biomass [2,27]. The pellets were produced by blending OPT with *A. mangium* wood to determine the optimum conditions. These conditions can be applied to produce high-quality blended biomass pellets. The comparison of the physical properties of pure pellets and blended biomass pellets at different percentage ratios (30, 50, and 70% OPT) is shown in Table 3. For pellet diameter, blending of OPT with *A. mangium* maintained the diameter between 8.0 to 8.5 mm. However, the pellet length of blended biomass pellets increased as the percentage of OPT increased. A good quality pellet must have a length less than 32 mm. The 30% OPT blended with *A. mangium* pellet had a length of 23.3 mm, meeting the standard requirement for commercial pellets. In addition, the size of pellets significantly affects their feeding rate and combustion efficiency. Shorter pellets have a significantly greater surface area subject to ignition and combustion reactions. This allows them to burn with more intensity than longer pellets, producing more heat in a shorter time span [28]. Increasing the length of pellets from 5.8 to 13.1 mm decreased the average burning temperature by 31% and flue gas temperature by

25%. However, longer pellets result in a cooler burn, making them less likely to cause ash melting and slagging [28]. The pelletizing pressure increases exponentially with pellet length, and the rate of increase depends on the biomass species and temperature [29]. The surface-area-to-volume ratio varies with the aspect ratio (diameter/ length) for cylindrical pellets, which directly affects heat transfer [30]. Therefore, the size and shape of pellets play a significant role in their feeding rate and combustion efficiency.

Table 3. Physical properties of wood pellet

Properties	100% *A. mangium*	30% OPT	50% OPT	70% OPT	100% OPT	Commercial pellet grade 1 [55]
Diameter (mm)	8.2	8.5	8.0	8.0	8.2	6-8
Length (mm)	33.4	23.3	47.0	42.9	51.2	<32
Bulk density (kg/m^3)	589	586	540	539	550	>500
Durability (%)	97.5	96.3	97.0	95.5	94.8	>97.5
Fines (%)	0.18	0.16	0.15	0.19	0.16	<1

The bulk density of biomass pellets is an important factor that affects their properties, such as storability, transportation costs, and handling efficiency. For transportation, higher bulk densities are needed to reduce logistic costs with less storage volume. Pelletizing is a method that increases the bulk density of biomass, making it more suitable for transportation and storage [31]. Bulk density is measured by the mass of the wood pellet divided by the total occupied volume. It is also affected by particle size, MC, and the size of the sample [31,32]. From Table 3, the bulk density for all blended biomass pellets has met the standard requirement for commercial pellets, which is more than 500 kg/m^3, with 30% OPT blended with *A. mangium* having the highest bulk density (586 kg/m^3). In comparison to 100% *A. mangium* pellets, the bulk density showed no significant difference, with only 0.51%. Generally, the bulk density of biomass pellets can be influenced by various factors such as the type of biomass, MC, die geometry, and process parameters [19,31,32]. According to Liu et al. [19], blending of different types of biomass materials, such as bamboo and pine particles, can improve the bulk density of biomass pellets.

Durability and fines were carried out to evaluate the mechanical resistance of the pellet during crushing, storage, or transportation from one place to another. The durability of 100% *A. mangium* was more than 97%. Meanwhile, the durability of 100% OPT and all blended biomass pellets were less than 97%. This difference was significant, as durability is a key parameter for ensuring pellets maintain their integrity throughout handling and usage. According to Balžekienė and Budzyte [56], durability values are essential for assessing the mechanical resistance of biomass pellets during transportation, with a standard durability requirement of over 97.5% for international transport. For fine content, the blended biomass pellets produced met the standard commercial pellet grade 1 requirements, which was less than 1.0% [55]. Lower fine content is associated with better quality pellets, indicating fewer particles that can lead to increased emissions and reduced combustion efficiency [57].

3.3 Effect of Blending of OPT and A. mangium on Its Chemical and Energy Properties

3.3.1 Proximate analysis

Proximate analysis is a crucial method used to evaluate the composition and properties of blended biomass pellets, as it provides information on the basic chemical components of the pellets. The results of proximate analysis can impact the performance, combustion characteristics, and overall efficiency of biomass pellets for various applications. Some key aspects of proximate analysis that affect biomass pellets include fixed carbon content, volatile matter, ash content, and MC [33]. The proximate analysis results presented in Table 4 only discuss the MC and ash content. The ash content of blended biomass pellets is an important parameter that affects their performance and combustion characteristics. According to Table 4, the MC of all blended biomass pellets was less than 10% after the pelletizing process. The ash content for all blended biomass pellets was higher than the commercial pellet standard (<0.7%). The ash content of OPT showed a slight difference when blended with *A. mangium*, with only a 9.1% reduction when 30% OPT was blended with *A. mangium*. This is in comparison to the ash content of pure pellets produced from *A. mangium*, which was 1.3%.

Table 4. Proximate analysis of wood pellet

Properties	100% A. mangium	30% OPT	50% OPT	70% OPT	100% OPT	Commercial pellet grade 1 [55]
MC (%)	6.2	6.3	5.5	5.9	6.1	<10
Ash content (%)	1.3	2.0	2.0	2.1	2.2	<0.7

The ash content of biomass pellets varies depending on the type of biomass and the production process [34,35]. The reduction in ash content when blending biomass pellets is crucial for maintaining combustion efficiency and minimizing environmental impact. Lower ash content leads to reduced emissions and less fouling in combustion systems, which is particularly important for small-scale systems that may lack advanced emission control technologies [50,51]. Zafirah et al. [47] studied the pellets produced from sawdust and reported that the ash content was 1.65%. Generally, the ash content of wood pellets typically ranges between 0.2% and 3.0%. Traditionally, the quality of wood pellets is classified according to their ash residues. According to the EN standard requirements, wood pellets can be classified into three (3) grades based on their ash content: A1, A2, and B. Grades A1, A2, and B have ash contents of less than 0.7%, 1.5%, and 3.0%, respectively. Grades 1 and 2 biomass pellets can be used for commercial or residential purposes without harming the boilers, while grade 3 pellets are only sold for industrial applications [36]. High ash content is not suitable for thermal conversion due to problems associated with ash removal, slagging, and deposit formation in the furnace [37,38]. One of the solutions to reduce ash content is through pre-screening of the feedstock before the pelletizing process [43].

3.3.2 Energy properties

Gross CV (GCV) and net CV (NCV) are important parameters for evaluating the energy content of biomass pellets. The GCV represents the total energy released during the complete combustion of a unit mass of the fuel. Meanwhile, the NCV accounts for the energy released after the water vapor formed during combustion is condensed and the heat of vaporization is recovered [39]. GCV of wood pellets were measured at constant volume on a dry basis using bomb calorimeter. The NCV of the pellets was calculated by subtracting 0.02441 times the hydrogen content concentration of the raw material (in %) from the GCV, as shown in Equation 1 below [54]. Therefore, the value of GCV is greater than that of NCV.

$$NCV = GCV - 0.02441H \tag{1}$$

where;

H: percentage of hydrogen in biomass (%)

GCV: Gross calorific value obtained from bomb calorimeter (MJ/kg)

According to Table 5, the GCV decreased with an increase in the percentage of OPT in blended biomass pellets. Only blended biomass pellets with less than 50% OPT blended with *A. mangium* met the standard requirement for commercial pellets (>18 MJ/kg). A 30% OPT blend with *A. mangium* had the highest GCV and NCV, which were 18.4 MJ/kg and 17.2 MJ/kg, respectively. The calculated NCV was less than the GCV by 7.0%. However, the trend of NCV values was similar to that of GCV, where an increasing percentage of OPT blended with *A. mangium* decreased the NCV. Aivars et al. [44] and Mohd Faizal et al. [45] reported that the CV of pellets produced from wood and EFB were 20.45 MJ/kg and 17.57 MJ/kg, respectively. This shows that the CV for non-woody biomass is less than that for woody biomass. Krishnan et al. [46] studied the use of adhesive binders to increase the energy properties of pellets and reported that kenaf was added to 15% starch-produced pellets with a CV of 46.2 MJ/kg. Zafirah et al. [47] reported that the CV of pellets produced from sawdust was 17.46 MJ/kg, almost similar to 100% OPT pellet. This is because the CV of pellets produced depends on the MC, where lower MC results in pellets with higher CV.

Pellets produced in this study had an MC of about 6.1% compared to the pellets reported by Zafirah et al. [47], which had an MC of 9.19%. Furthermore, the increase in GCV from 17.4 to 18.4 MJ/kg when blending 30% OPT with *A. mangium* demonstrated the potential for producing high-energy biomass pellets. This enhancement can lead to more efficient energy production in both residential and industrial applications, as higher energy density translates to better performance in combustion systems [49]. The ability to produce high-quality pellets that meet commercial standards can enhance market competitiveness. As the demand for renewable energy sources increases, the development of biomass pellets that meet or exceed the quality of traditional fuels can position producers favorably in the energy market [52,53]. This focus on quality ensures compliance with industry standards and attracts consumers increasingly seeking reliable and efficient energy solutions. Furthermore, high-quality pellets contribute to improved combustion efficiency and reduced emissions, aligning with global sustainability goals.

Table 5. Energy properties of blending biomass pellets of OPT and *A. mangium*

Properties	100% A. mangium	30% OPT	50% OPT	70% OPT	100% OPT	Commercial pellet grade 1
GCV (MJ/kg)	18.7	18.4	18.1	17.4	17.4	>18
NCV (MJ/kg)	17.6	17.2	17.1	16.3	16.3	-

3.4 Effect of Blending of OPT and A. mangium on Its Elemental Properties

Minor and trace elements present in wood pellets can have significant effects on their combustion behavior and ash characteristics. The elements in blended biomass pellets, in comparison with pure pellets and commercial pellets, are shown in Table 6. The presence of these elements in blended biomass pellets influences the formation and disposal of ash and affects their ash fusion behavior, which in turn influences slagging in furnaces [36]. Referring to Table 6, the chlorine (Cl) content in all blended biomass pellets was within the reported range for commercial pellets at less than 0.05%. Meanwhile, the sulfur (S) content increased as the percentage of OPT blended with *A. mangium* increased. However, 30% and 50% OPT blends with *A. mangium* met the standard requirement for commercial pellets, which should have a content of less than 0.05%. Increased concentrations of Cl and S content could result from chemical contamination by insecticides, adhesives, glues, or wood preservatives in the raw material or additives. The concentrations of these elements should be limited due to their negative influences on the combustion process. High amounts of these elements can cause emissions-related problems (HCl and SOx), deposit formation, and corrosion. High Cl content in biomass pellets could lead to the formation of hydrochloric acid during combustion. As a result, it could cause corrosion and fouling in boilers, leading to reduced efficiency and increased maintenance costs [40].

Regarding the N content, 100% OPT pellets did not meet the standard requirement compared to 100% pellet from *A. mangium*, with a 94.7% difference. Blending 30% OPT with *A. mangium* decreased the N content to 0.29%, directly meeting the standard requirement of having N content less than 0.30%. The increase in these values could be explained by the use of OPT bark. High N content could also indicate the use of prohibited substances on OPT, such as fertilizers, resulting in increased NOx emissions [41]. Instead of minor elements, there are also trace elements that affect the properties of blended biomass pellets. From Table 6, it was found that the concentrations of, cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni) and arsenic (As) in all blended biomass pellets were below the limit. Mercury (Hg) content was not detected in any of the blended biomass pellets. However, the concentration of chromium (Cr) in all samples exceeded the concentration limit. It is generally stated that the heavy metal content was higher in bark compared to the other biomass. Therefore, it can be assumed that the bark of the raw materials was mixed together during the wood pellet production.

Table 6. Elemental Analysis of wood pellet

Element	100% *A. mangium*	30% OPT	50% OPT	70% OPT	100% OPT	Commercial pellet grade 1
Cl (%)	0.02	0.02	0.02	0.01	0.02	<0.05
N (%)	0.19	0.29	0.38	0.43	0.37	<0.30
S (%)	0.01	0.04	0.04	0.06	0.07	<0.05
As (mg/kg)	0.14	0.14	0.10	0.11	0.11	<1
Pb (mg/kg)	0.55	0.73	0.85	0.46	2.23	<10
Cd (mg/kg)	0.01	0.01	0.01	0.01	0.01	<0.5
Cr (mg/kg)	13.62	18.84	19.84	17.42	20.44	<10
Zn (mg/kg)	0.03	0.18	0.25	0.39	0.22	<100
Ni (mg/kg)	0.08	0.07	0.12	0.06	0.06	<10
Hg (mg/kg)	ND	ND	ND	ND	ND	

ND; Not detectable

Additionally, the increased levels of heavy metals may be due to the recycling of partly chemically treated wood. In general, low levels of heavy metals in wood pellets are important because they strongly impact ash quality, particulate emissions, and recycling and disposal. Therefore, the content should be limited, especially for utilization in small scale systems, which are usually not equipped with dust precipitation devices.

4. CONCLUSION

Blending OPT with *A. mangium* for pellet production has shown promising results. The pellet properties of OPT were improved by blending with fast-growing woody biomass species like *A. mangium* at different weight ratios. High-quality blended biomass pellets were produced by mixing 30% of OPT with *A. mangium* biomass, where the energy density increased significantly from 17.4 to 18.4 MJ/kg, and the ash content decreased slightly from 2.1 to 2.0%. The physical properties of all OPT blended with *A. mangium* met the standard requirements for commercial pellets, making it promising for future development as an alternative substitute for fossil energy. This research also provides valuable insights into the potential of blending OPT with *A. mangium* for fuel pellet production, offering a sustainable and efficient use of biomass resources. Optimizing the pellet produced from OPT and *A. mangium* can help to identify the highest quality pellets compared to the results obtained in this research, which targets optimizing the parameter conditions in terms of blending ratio, sample loading, die internal diameter, temperature, and maximum applied force and pressure.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORS CONTRIBUTION

Rafidah J. (Conducting experiment, Data curation, Writing-original draft)

Hashim B. (Conceptualization, Visualization, Supervision)

Mahanim S.M.A. (Methodology, Formal analysis, Writing-review)

Tumirah K. (Methodology, Formal analysis, Writing-review)

Puad E. (Conducting experiment, Methodology, Formal analysis, Writing-review)

Shaharuddin H. (Writing-review, Resources)

Nicholas A.L. (Writing-review, Resources)
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Rickey A.D. (Writing-review, Resources)

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