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UTILIZATION OF SAGO WASTE IN POLYMER COMPOSITES

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Abstract:

Sago has been known as a natural reinforcement material. Therefore, the waste should still have the same composition. The fibre produced from sago palm is a by-product from the sago industry. According to Department of Statistics Malaysia (DOSM), in 2023 Sarawak had exported 35,000 metric tonnes of sago. This paper studies the use of sago palm waste as natural reinforcement in polymer composites. The main aim is to reduce agricultural waste and at the same time, develop an eco-friendly alternative for reinforcement material. The sago waste fibres were processed and combined with epoxy resin to produce composite samples. The hand lay-up method was used. Samples with fibre contents of 5%, 10% and 15% by weight were produced and tested for tensile and flexural strength according to ASTM D3039 and ASTM D790 standards. The results showed that the 5% and 10% fibre contents produced the highest tensile strength and achieved the best flexural strength respectively. The findings have proven that sago waste fibres can be utilized. Lightweight and sustainable composites suitable for construction and aesthetic applications can be produced by using sago waste fibres. This research demonstrates the potential of sago palm fibre as a renewable alternative to synthetic reinforcement materials.

Keyword:

Synthetic Material, Mechanical, Materials, IR4.0



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Introduction

Aligned with the current global eco-friendly agenda, sustainable materials have been sought after as alternatives to non-biodegradable synthetic fibres in polymer composites. Conventional materials currently used such as carbon fibres and glass, offer high strength but also pose significant environmental concerns. These materials tend to be non-recyclable and high cost for both during the material's production or disposal. As industries look for greener solutions, natural fibres have become a leading material option due to the natural fibre's availability and density attribute.

In Sarawak, Malaysia, the sago palm industry plays a major role in the local agricultural sector. Though Sarawak was able to produce multiple products using sago palm, the industry also unknowingly increases the waste produced by the said palm. The waste, known as sago dregs, is a fibrous waste that is often discarded or left to rot without any use, this usually leads to environmental problems, including water pollution from the decomposition runoff. The waste material, known to have cellulose, hemicellulose and lignin can also provide good bonding and strength if used in composite materials.

This study will focus on the utilization of sago palm waste fibre as a reinforcement material in epoxy resin composites. This study supports sustainability and the efficiency of the resources by converting the agricultural waste into composite materials. The main aim is to evaluate the mechanical properties of the composite when sago palm waste fibre is added.

Literature Review

Composite Materials

Composite materials are now widely acknowledged for their enhanced properties, enabling its use across a broad range of applications. Over the past two decades, research has demonstrated that composite materials offer significant improvements in structural, mechanical, and tribological performance, positioning them as strong alternatives to traditional materials (Rajak et al., 2019).

Composite materials consist of two or more distinct constituent materials with significantly different physical and/or chemical properties. When combined, these materials work synergistically to create a composite with characteristics that are superior to those of the individual components. Many new composites have been developed in the last few decades, some of which have very valuable qualities (Amin et al., 2019). Over time, the development of stronger materials led to the emergence of fibre-reinforced composites, which not only offered enhanced performance but also scalability for various applications (Rajak et al., 2019).

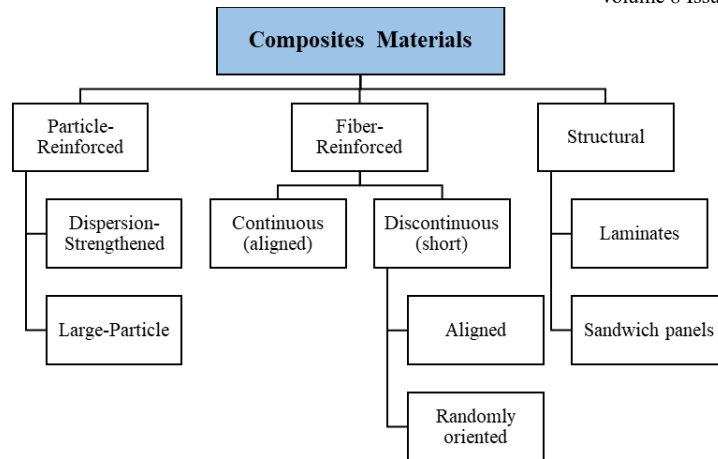


Figure 1: A Basic Structure for Classifying Composite Materials

Source: (Fiber-Reinforced Polymer Composites: Manufacturing, Properties, and Applications by Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E.)

Polymer Matrix Composite and its Application

Polymer matrix composites (PMCs) remain one of the most effective methods for enhancing the properties of polymers. These composites are typically categorized into two matrix types: thermoset and thermoplastic. Although thermoset-based composites are more commonly used, thermoplastic-based composites are gaining popularity due to their advantages, such as lower manufacturing costs, high strength, low moisture absorption, elimination of curing processes, ease of reprocessing, and high-temperature resistance (Oladele et al., 2020).

PMCs are commonly used in industries such as aerospace, sports, healthcare, transportation, and construction. As one of the earliest and most rapidly advancing material types, composite materials offer enhanced properties that make them highly suitable for use in spacecraft, rockets, and aircraft (Hassan et al., 2021). In construction, they are used to produce structures with excellent corrosion resistance. For centuries, concrete has been the primary material widely used in construction. However, its strength and durability tend to decline over time due to various factors that affect its structural performance. While concrete offers excellent compressive strength, it is inherently weak in tension. To address this limitation, PMCs have emerged as a popular alternative to traditional metal-based engineering materials. PMCs offer several advantages, including being lightweight, cost-effective to produce, easy to shape, and having high tensile and flexural strength along with good elasticity (Yuhazri, Zulfikar, & Ginting, 2020).

Hardener

In determining the final physical and mechanical properties of epoxy resin, curing agents are fundamental as curing agents governs the reaction kinetics, gelation time, viscosity profiles and the ultimate degree of cure. These agents are generally classified into three primary categories depending on the chemical reaction each of the agents with the epoxy matrix. Active Hydrogen Compounds class is the most commercially significant. This agent includes amines, amides, hydroxyls and acid anhydrides facilitate curing through polyaddition reactions. The second class is Catalytic Initiators (Anionic and Cationic), different from polyaddition agents, catalytic initiators promote the homo-polymerization of epoxy resin. The third curing agent is

Reactive Cross-linkers. These high-equivalent-weight agents, such as phenol, urea-formaldehyde and melamine resins, function by self-condensing or reacting with the secondary hydroxyl groups present along the epoxy backbone.

Natural Fibre

The integration of natural fibres (NFs) as reinforcements within epoxy matrices represents a pivotal advancement in sustainable bio composites, primarily attributed to their favourable specific strength-to-weight ratios and low density. High-cellulose content reinforcements, such as flax and jute, demonstrate significant potential for improving the tensile and impact performance of the resulting polymer network. However, the efficacy of these reinforcements is often constrained by the inherent polarity mismatch between the hydrophilic lignocellulosic fibres and the hydrophobic epoxy resin, which can impede interfacial bonding. Addressing this challenge requires targeted chemical modifications, such as alkalization, or the adoption of hybridization strategies to enhance interfacial adhesion and optimize stress transfer mechanisms. Such treatments are critical for ensuring environmental durability and achieving the mechanical benchmarks required for rigorous industrial applications (Ali et al., 2023).

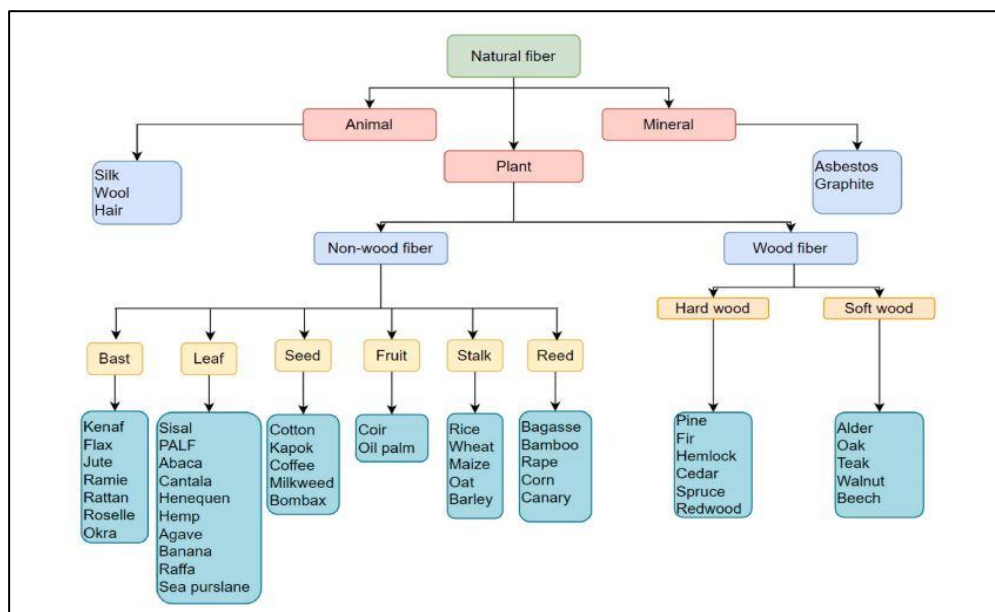


Figure 2: Types and Classifications of Natural Fibres Involve in Polymer Matrix Composites

Source: (Potential of lignocellulosic fibre reinforced polymer composites for automobile parts production: Current knowledge, research needs, and future direction by Musa, A. A., & Onwualu, A. P.)

The waste from the sago palm used in this research is depicted in Figure 3. The part of the fibre utilized is from the previously processed sago tree, specifically the outer, middle, and inner sections of the trunk.

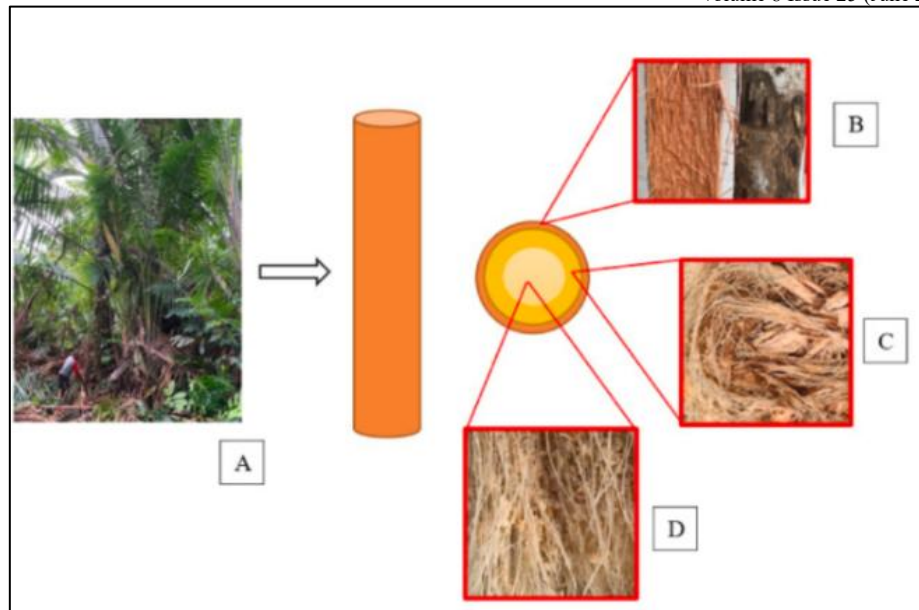


Figure 3: Parts Of the Sago Tree Used: (A) Tree Trunk, (B) Bark, (C) Middle Fibre, And (D) Inner Fibre

Source: (Characterization of Sago Tree Parts from Sentani, Papua, Indonesia for Biomass Energy Utilization by Susanto, B., Tosuli, Y. T., Adnan, Cahyadi, Nami, H., Surjosatyo, A., Alandro, D., Dio Nugroho, A., Ibnu Rashid, M., & Akhsin Muflikhun, M.)

Table 1 Compositional Sago Palm Fiber(Susanto et al., 2024)

Natural Fiber	Moisture content (%)	Starch (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractive (%)	Ash (%)
Sago Palm Fiber	3.50 ± 0.17	38.41 ± 1.36	14.31 ± 1.48	17.45 ± 0.90	4.83 ± 1.04	2.82 ± 1.36	2.74 ± 0.42

Source: (Characterization of Sago Tree Parts from Sentani, Papua, Indonesia for Biomass Energy Utilization by Susanto, B., Tosuli, Y. T., Adnan, Cahyadi, Nami, H., Surjosatyo, A., Alandro, D., Dio Nugroho, A., Ibnu Rashid, M., & Akhsin Muflikhun, M.)

Methodology

This outlines the methodology used in detailing the raw materials, fabrication method and testing procedures.

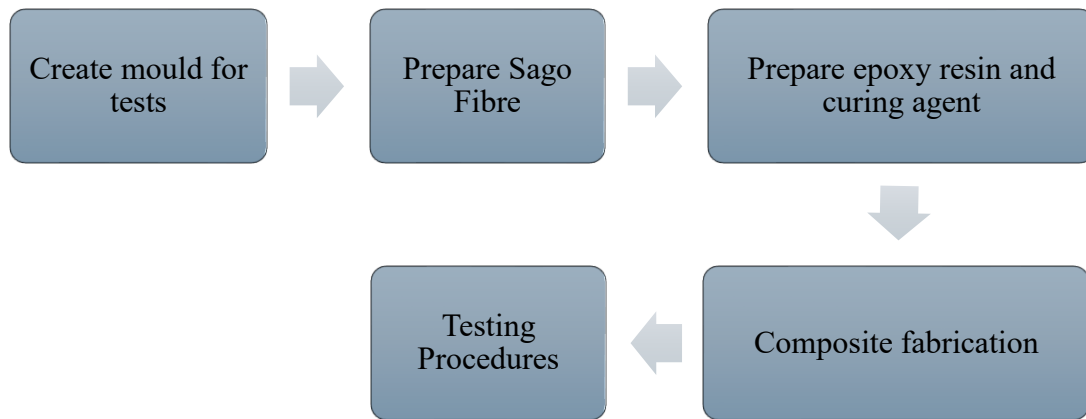


Figure 4: Process Flowchart for Composite Fabrication

Mould Preparation

A makeshift mould made of double-sided tape was used to help moulding the composite for the tensile test sample and the flexural test sample. The moulds' sizes were 127 mm in length, 64 mm in width and 3 mm of thickness for the tensile test. As for the flexural test, the moulds are 250 mm in length, 12.5 mm in width and 3 mm thickness.



Figure 5: Tensile Test Sample Mould (left) and Flexural Test Sample Mould (right)

Composite Fabrication

Composite fabrication starts by preparing the sago fibre. Sago waste obtained from small sago product's manufacturer were washed thoroughly to remove any impurities. This process is crucial in order to ensure the fibre used are free from unwanted dirt or dust. Next the sago fibres were sun dried properly. Proper drying is essential to prevent moisture-related defects and to ensure better bonding between the sago fibre and the epoxy resin during the composite fabrication process.



Figure 5: Drying process of Sago Fibre (left) and Sago Fibre after drying process (right)

Next, all dried sago fibres, epoxy resin and the curing agent is weighted according to the predetermined weight based on the calculated composition for the composite. **Table 2** displays the composition of Sago Fibre, Epoxy Resin, and Curing Agent used in preparing the tensile test samples for this study. The sample size for tensile test samples is 250mm (length), 150mm (width) and 3mm (thickness) following American Society for Testing and Materials, ASTM D3039/ D3039M standard. **Table 3** displays the composition of Sago Fibre, Epoxy Resin, and Curing Agent used in preparing the flexural test samples for this study. The sample size for tensile test samples is 127mm (length), 12.7mm (width) and 3.2mm (thickness) following ASTM D790 standard. The composite then produced by using the hand lay-up method based on the sizes for the test samples accordingly.

Table 2: Composition of Sago Fibre, Epoxy Resin, and Curing Agent used in Preparing the Tensile Test Samples

Sample	Composition (wt. %)		Sago Fibre (g)	Epoxy Resin (g)	Curing Agent (g)
	Sago Fibre	Epoxy Resin+ Curing Agent			
A	5	95	6.47	92.2	30.7
B	10	90	12.94	87.35	29.12
C	15	85	19.41	82.4	27.50

Table 3: Composition of Sago Fibre, Epoxy Resin, and Curing Agent used in Preparing the Flexural Test Samples

Sample	Composition (wt. %)		Sago Fibre (g)	Epoxy Resin (g) + Curing Agent (g)
	Sago Fibre	Epoxy Resin+ Curing Agent		
A	5	95	0.31	5.94
B	10	90	0.66	5.94
C	15	85	1.05	5.94

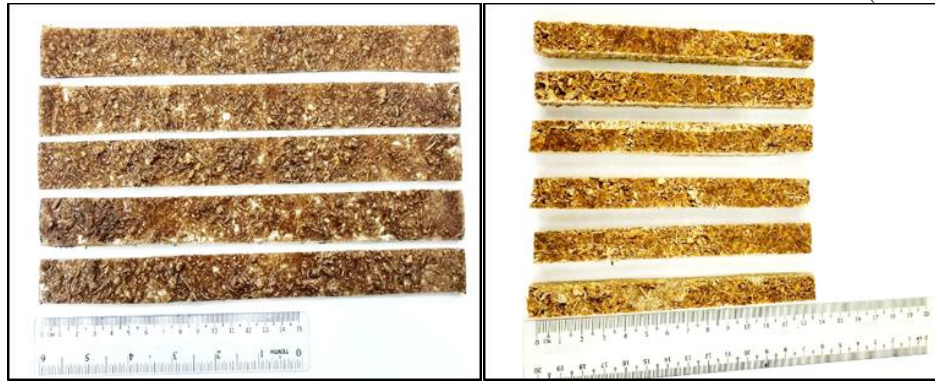


Figure 6: Tensile Samples (left) and Flexural Samples (right)

Testing Procedures

Tensile Test and Flexural Test were performed using Universal Testing machine model Shidmazu AG-X following ASTM D3039/ D3039M and ASTM D790 standard respectively.



Figure 7: Tensile Test (left) and Flexural Test (right)

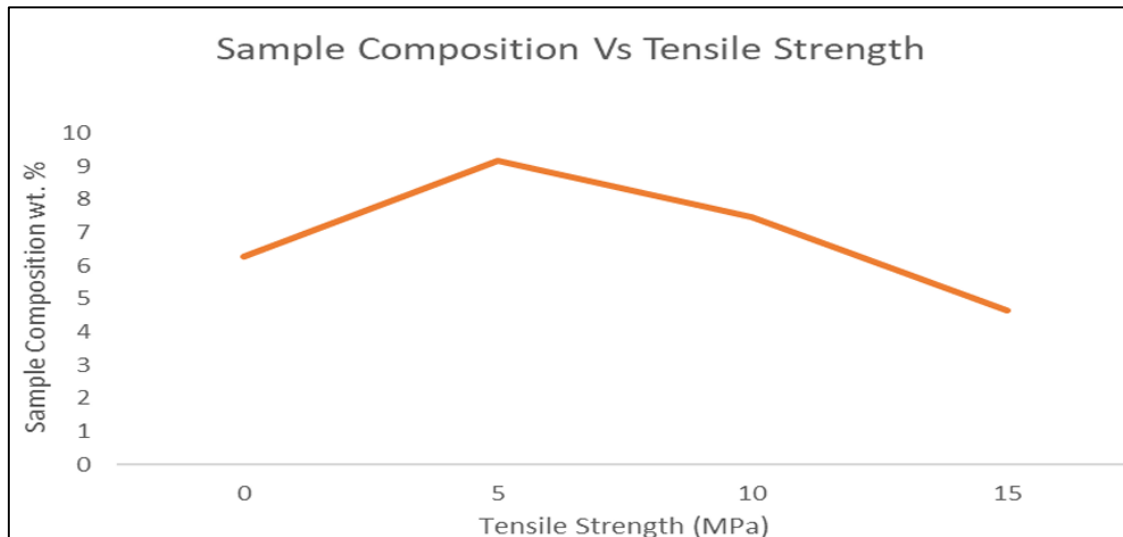
Results and Discussion

Tensile Test Result

The highest tensile strength of 9.145 MPa was achieved at 5 wt.% sago palm fibre and 95 wt.% epoxy resin, indicating optimal fibre-matrix interaction. Increasing the fibre content beyond 5 wt.% led to reduced tensile strength, likely due to fibre agglomeration and poor matrix wetting, which weaken stress transfer between fibre and matrix as shown in **Table 4**. **Figure 8** illustrate the graph sample composition versus tensile strength. This finding aligns with the theory that an optimum fibre loading enhances mechanical performance, while excessive fibre causes defects in the composite structure (Akil et al., 2011).

Table 4: Tensile Test Result

Samples composition wt %	Tensile Strength, (N / mm ² , Mpa)
0	6.260
5	9.145
10	7.450
15	4.636

**Figure 8: Graph Sample Composition versus Tensile Strength*****Flexural Test***

Flexural strength refers to a material's capacity to withstand bending forces without fracturing. In this study, the highest flexural strength recorded was 7.956 MPa, achieved with a composition of 10 wt.% sago palm fibre and 90 wt.% epoxy resin as shown in Table 5. This finding suggests that the incorporation of natural fibres enhances the composite's resistance to bending. Natural fibres improve stress transfer between the fibre and matrix, contributing to better mechanical performance in fibre-reinforced composites (Jawaid et al., 2011). Figure 9 illustrate the graph of sample composition versus flexural strength.

Table 5: Flexural Test Result

Samples composition wt %	Flexural Strength, (N / mm ² , Mpa)
0	0.083
5	7.159
10	7.956
15	1.106

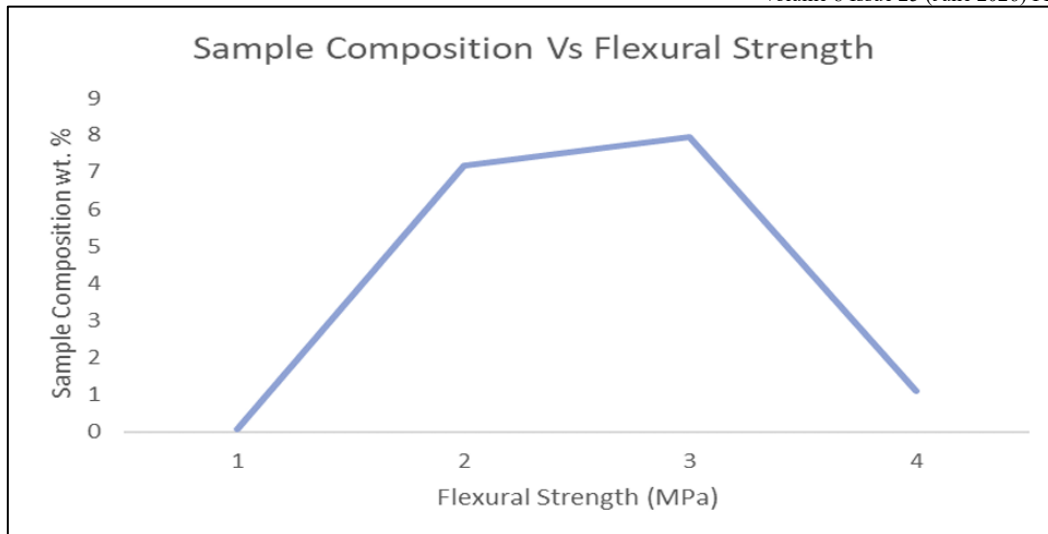


Figure 9: Graph Sample Composition Versus Flexural Strength.

Discussion

Both mechanical tests showed that the strength of the composites heavily relying on the amount of sago fibre used. The highest tensile strength recorded was 9.145 MPa with 5% fibre content, while the highest flexural strength recorded was 7.956 MPa with 10% fibre content. Beyond these levels, the strength decreased due to poor resin-fibre bonding as well as uneven fibre distribution. Both results are aligned with other studies on natural fibre composites. This suggests that moderate fibre addition leads to optimal mechanical performance. From a sustainability perspective, theory of sago palm waste can serve as an effective natural reinforcement material has been proven. Although the mechanical strength is lower than synthetic fibres, the environmental and economic benefits make sago fibre composites a viable alternative for non-structural applications.

Conclusion

This study has successfully demonstrated sago palm waste can be utilized in producing polymer composites with reasonable mechanical strength. Samples made using the hand lay-up method was effective for fabrication. The best tensile strength and flexural strength occurred at 5% and 10% fibre respectively. This study highlights that agricultural waste, in this case sago dregs, can indeed be utilized as other useful materials thus reducing environmental impact and supports sustainable development.

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- Author Contribution Statement:** All authors contributed significantly to the development of this manuscript. Ts. Syarafadila Ezurida binti Shaari was responsible for the conceptualization, methodology, and overall supervision of the study. Farihana binti A.Rahman handled data collection, analysis, and interpretation of results. Verawaty binti Ismail contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.
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