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Assessing the Performance and Biodegradability of Sargassum sp. Bioplastics as an Alternative to Conventional Plastics

Muhammad Emir Fayed Mohd Fuaad[1], Dzulaikha Khairuddin[1,2*], Nasaei Zainuddin[3]

[1]*Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam Selangor*
[2]*Watermicropath Research Group, Universiti Teknologi MARA, 40450 Shah Alam Selangor*
[3]*Faculty of Art & Design, Universiti Teknologi Mara, 40450 Shah Alam Selangor*

*Corresponding author: dzulaikha@uitm.edu.my

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Abstract

The increasing environmental concerns associated with conventional plastics have driven the search for sustainable alternatives. This study explores the potential of Sargassum sp., a brown seaweed as a raw material for bioplastic production. Sargassum sp. is abundant in west ocean in Malaysia, renewable and often considered a waste material in coastal areas, making it an attractive candidate for sustainable applications. The research focuses on assessing the performance and environmental impact of bioplastics derived from Sargassum sp. compared to conventional petroleum based plastics. The methodology includes the collection and preparation of Sargassum sp. samples, bioplastics synthesis through extraction and formulation techniques and evaluation of mechanical, thermal, and physical properties. Additionally, a comprehensive environmental impact assessment is conducted using an emphasizing biodegradability. The performance of Sargassum sp. bioplastics is benchmarked against standard plastics to determine their suitability for practical applications. The bioplastic samples also endured longer loading durations (up to 468.0 seconds), indicating better strain endurance compared to synthetic plastic, which failed as early as 216.0 seconds. This highlights the superior mechanical performance of the bioplastic. The bioplastic exhibited excellent biodegradability, fully decomposing within 28 days in soil, but showed extremely high water absorption exceeding 1000%, attributed to the hydrophilic nature of alginate. This research highlights the potential of utilizing marine biomass to address plastic pollution while promoting sustainable material development. The outcomes aim to contribute to the advancement of eco-friendly alternatives towards reducing reliance on conventional plastics.

Keywords: *Bioplastics; Sargassum sp; sustainable materials; biodegradability; eco-friendly*

1. Introduction

Plastic poses significant threats to the environment, human health, and sustainability due to its long degradation time, leading to persistent pollution. Microplastics have been found in soil, air, oceans, and even human tissues, raising health concerns. Marine wildlife suffers from ingestion and entanglement, while plastic production contributes to greenhouse gas emissions (Lim et al., 2021).With low recycling rates, most plastics end up in landfills or are incinerated. Sustainable alternatives like seaweed-based bioplastics offer a promising solution to these challenges (Waseem et al., 2023).

Sargassum sp. is a genus of brown seaweed found abundantly in marine environments, particularly in tropical and subtropical waters. Sargassum sp., which is well-known for its quick growth and high biomass production, has drawn interest as a sustainable resource for a range of industrial uses, including the manufacturing of bioplastics (Jayasinghe et al., 2022). It was chosen as a sustainable bioplastic because it is easily accessible as a feedstock and contains alginate, one of its active ingredients that is essential for the production of bioplastics. Sargassum sp., a brown macroalgae, is rich in sodium alginate which are a natural, water-soluble hydrocolloid extracted from its cell walls (Hamrun et al., 2022). Sodium alginate is valued for its ability to form flexible, biodegradable films, making it ideal for bioplastic production (Mohammed et al., 2023b). Its excellent film-forming and moisture-absorbing properties support the development of environmentally friendly alternatives to conventional plastics. The abundance of sodium alginate in Sargassum sp. highlights its potential as a sustainable raw material for bioplastics.

The performance of Sargassum sp. bioplastics is influenced by several factors, including the chemical composition of the algae, the methods used for processing, and the intended application of the bioplastic. The mechanical strength of Sargassum sp.-based bioplastics is largely dependent on the extraction and processing techniques used, as well as the chemical modifications made to the biopolymer (Alallam et al., 2025; Lim et al., 2018). Sodium alginate, one of the key biopolymers in Sargassum sp., is capable of forming films with varying degrees of strength and flexibility (Mohammed et al., 2023b). However, when compared to conventional synthetic plastics, bioplastics made from alginates have limitations due to their high stiffness, high brittleness, low deformability, and moisture sensitivity. Nevertheless, these issues can be resolved by combining reinforcement materials, plasticisers, and additional natural polymers in composite technology (Mohammed et al., 2023b). Although bioplastics made from Sargassum sp. typically have poorer mechanical qualities than traditional plastics like polyethylene or polypropylene, developments in combining Sargassum sp. with other natural polymers or reinforcing agents like cellulose or starch and plasticizers can increase the bioplastics' strength and durability (Langit et al., 2019). When considering alginate composites for food packaging, their thermal properties need to be taken into account. In terms of sustainability and thermal qualities, alginate-based bioplastics offer a promising substitute, particularly when combined with plasticisers like glycerol (Santana et al., 2024).

The biodegradability of Sargassum sp.-based bioplastics is one of their most important environmental benefits, as it tackles the ongoing problem of plastic pollution. Under the influence of microorganisms, bioplastics made from Sargassum sp. naturally decompose into harmless byproducts like water, carbon dioxide, and biomass, in contrast to conventional plastics made from petroleum-based products, which can take hundreds of years to decompose (Elkaliny et al., 2024). This procedure lessens the amount of non-biodegradable waste that ends up in landfills and the environment, especially in marine ecosystems where plastic waste seriously endangers wildlife. Sargassum sp. bioplastics are biodegradable mainly because of the seaweed's natural composition, which is high in polysaccharides like alginate (Samuel et al., 2024). Microbes easily break down these biopolymers, resulting in a thorough and non-toxic breakdown. Sargassum sp. bioplastics are therefore perfect for uses such as single - use packaging, where disposal's negative environmental effects are a major concern.

Bioplastics offer a sustainable alternative to conventional plastics, being derived from renewable sources such as corn (Nasir and Othman, 2021), sugarcane (Nair, 2024), potatoes (Mohammad Azmin et al., 2024), and more recently, seaweed (Torrejon et al., 2025). Unlike petroleum-based plastics, which take centuries to degrade (Prasteen et al., 2018), bioplastics can decompose faster under suitable conditions (Narancic et al., 2020). Seaweed-based bioplastics are emerging as a promising alternative due to seaweed’s rapid growth, renewability, and minimal resource needs (Lomartire et al., 2022). Sargassum sp., in particular, is abundant in coastal regions and rich in polysaccharides like alginates (El Islam, 2024). Often viewed as a coastal nuisance, Sargassum presents an opportunity for sustainable bioplastic production, transforming waste into valuable material (Maurer et al., 2021).

This study investigates the performance and environmental impact of bioplastics derived from Sargassum sp., focusing on their mechanical properties, water absorption and biodegradability. The research also evaluates degradation under varying environmental conditions, such as moisture, UV exposure, and temperature, to assess their suitability for applications including packaging, agricultural films, and disposable products.

2. Methodology

2.1 Study location and sample collection

Sargassum sp. samples were collected from Pantai Bagan Pinang, Port Dickson, Negeri Sembilan, due to its ecological suitability and natural abundance of seaweed as shown in Figure 1. Collection was carried out manually during low tide using non-invasive methods to minimize environmental disturbance. Only healthy, mature specimens were selected, while degraded or contaminated samples were excluded. Samples were rinsed on-site with seawater to remove sand and debris, then transported fresh to the laboratory for further processing.

Figure 1. (a) Location of Port Dickson location in Peninsular Malaysia; (b) Pantai Bagan Pinang located at Port Dickson, Negeri Sembilan; (c) Sargassum sp. seaweed collected in Pantai Bagan Pinang, Negeri Sembilan.

2.2 Alginate extraction

Collected Sargassum sp. was thoroughly washed to remove debris, salt, and sand. The cleaned seaweed was then oven-dried at 60 °C to eliminate moisture. Once dried, it was ground into a fine powder to increase surface area and facilitate efficient alginate extraction. Powdered Sargassum sp. was first pretreated with a formaldehyde solution to remove pigments and reduce

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tissue rigidity. For extraction, 10 g of seaweed powder was added to 250 mL of distilled water containing 0.5 g sodium carbonate (Na_2CO_3), then stirred at 50 °C for 2 hours to convert alginic acid into soluble sodium alginate. The mixture was filtered using vacuum filtration to separate solid residues. The clear alginate solution was collected and stored in a sealed container to prevent contamination. The filtered alginate solution was dried in a shallow tray at 60 °C to form a thin film, followed by further drying at 50 °C to ensure complete dehydration. The dried film was then ground into a fine powder and stored in an airtight container.

2.3 Alginate film solution

An alginate solution was prepared by gradually adding 2 g of sodium alginate into 100 mL of distilled water in a 250 mL beaker, with continuous stirring for 60 minutes at approximately 50 °C to aid dissolution and prevent clumping. Once a uniform solution was achieved, 2 mL of glycerol was added as a plasticizer and stirred for an additional 5 minutes. The addition of glycerol improves the flexibility and mechanical properties of the resulting bioplastic by disrupting intermolecular forces within the alginate matrix. A precise alginate-to-plasticizer ratio was maintained to ensure a balance between strength and flexibility. The solution was then left to rest for 10 minutes to release any trapped air bubbles.

2.4 Film casting and crosslinking

The prepared alginate solution was cast using the solvent casting method. A volume of 8–10 mL was poured into clean moulds and evenly spread by gently tilting the mould surface. The solution was left undisturbed for 10 minutes to settle and allow trapped air bubbles to escape. Films were then air-dried at room temperature to promote uniform drying and structural stability. For the crosslinking step, a 10% w/v magnesium chloride ($MgCl_2$) solution was prepared by dissolving 10 g of $MgCl_2$ in distilled water and adjusting the volume to 100 mL. A 5% w/v calcium chloride ($CaCl_2$) solution was similarly prepared with 5 g of $CaCl_2$ in 100 mL of distilled water. Both solutions were stored in clean, labelled containers.

For the crosslinking process, a 10% (w/v) magnesium chloride ($MgCl_2$) solution was prepared by dissolving 10 g of $MgCl_2$ in distilled water and adjusting the volume to 100 mL. A 5% (w/v) calcium chloride ($CaCl_2$) solution was prepared similarly by dissolving 5 g of $CaCl_2$ in 100 mL of distilled water. A blended crosslinker was freshly prepared by mixing 6 mL of the $MgCl_2$ solution with 4 mL of the $CaCl_2$ solution (60:40 volume ratio). The mixture was gently stirred for 30 seconds and evenly sprayed onto the surface of the cast alginate film. The film was allowed to crosslink at room temperature for 60 minutes, followed by air drying at 25–30 °C for 48 hours. After drying, the bioplastic film was carefully peeled from the mould and inspected for physical integrity.

2.5 Assessment of mechanical, biodegradability, and absorptive properties of Sargassum bioplastics

Tensile strength and elongation at break of the bioplastic films were tested according to previous method with slight modification (El Islam, 2024). Tensile strength was tested using a textile tensile machine (UTS-Tex-Plus, UTS International, China), following the ASTM D882 standard (El Islam, 2024) as shown in Figure 2 (a). Samples were prepared in dumbbell-shaped with standard dimensions, and their width, thickness, and gauge length were measured using a vernier caliper. The tensile machine was calibrated and set to a constant crosshead speed of 1 mm/min. Each specimen was clamped securely to ensure accurate alignment and prevent slippage. Tensile force was applied until the specimen fractured, and the force-extension data were recorded. Tensile strength was calculated by dividing the maximum force by the original cross-sectional area, while elongation at break was determined as the percentage increase in length at the point of fracture. Figure 2 (b) illustrate the setup and testing procedure.

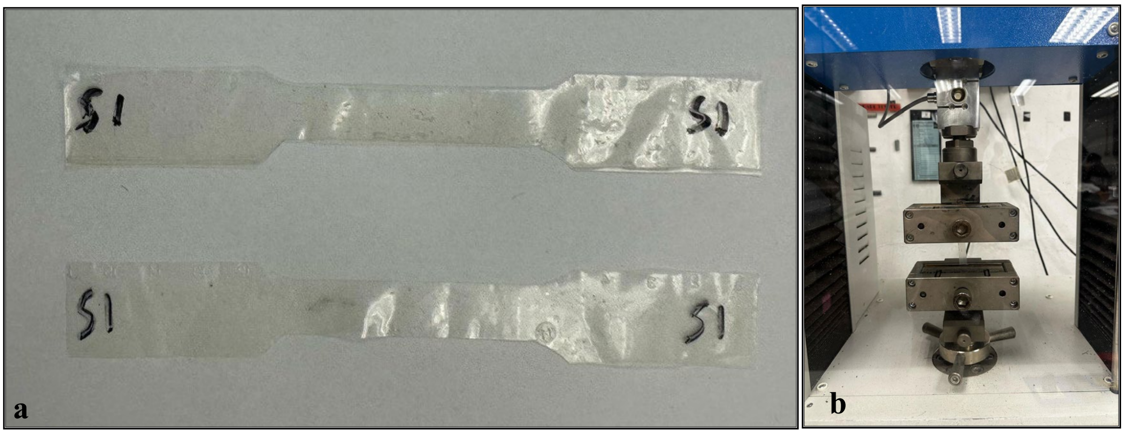

Figure 2. (a) Dumbbell-shaped alginate film specimen for tensile testing; (b) Tensile test setup using UTS-Tex-Plus machine.

Biodegradability was evaluated using a soil burial method following Papa et al. (2023), with slight modification. Garden soil was sieved and placed in trays, and bioplastic samples (20 cm in length) were buried at a depth of approximately 1 cm. The samples were maintained at room temperature for 28 days, with soil moisture periodically adjusted to support microbial activity. Visual observations were recorded at selected intervals (Day 0, 7, 14, 21, and 28) to assess physical degradation, including discoloration, surface erosion, cracking, and loss of structural integrity.

Water absorption behaviour was assessed by immersing bioplastic samples in distilled water following Kasmuri and Zait (2018), with extended immersion durations. Three uniform film samples (20 cm in length) were weighed to obtain their initial dry weight and then immersed in 500 mL of distilled water at room temperature. The samples were removed at predetermined intervals of 2, 7, 14, 21, and 28 days, gently blotted to remove surface water, and weighed to determine the wet weight. Water absorption was calculated based on the percentage increase in mass relative to the initial dry weight.

3. Results and Discussion

3.1 Determination of Tensile Strength

Based on previous research findings, it has been observed that the use of *Sargassum sp.* as a raw material for bioplastics has demonstrated promising results in terms of sustainability and performance (Mohammed et al., 2023a). Studies indicate that *Sargassum sp.*, with its high polysaccharide content which is alginates serves as an excellent biopolymer source for producing bioplastics (Marcin et al., 2024). Therefore, based on study by Marcin et al., 2024, it can be concluded that the expected result regarding tensile strength in *Sargassum sp.* bioplastic can be derived by comparing the effectiveness of different concentration of plasticizer.

This study observed that the maximum force recorded for Sargassum sp. bioplastic was 2.84 N, outperforming conventional plastic at 1.86 N as shown in Table 1 and Table 2. Additionally, the bioplastic showed greater elongation (17.33%) compared to conventional plastic (8.00%), indicating higher flexibility. The bioplastic samples also withstood longer loading durations (up to 468.0 seconds), suggesting better strain endurance than synthetic plastic, which failed as early as 216.0 seconds. These findings highlight the superior mechanical behaviour of Sargassum sp. bioplastics. Figure 3 shows the force versus elongation graph comparing conventional plastic samples and Sargassum sp. bioplastic samples.

Table 1. Tensile strength results of two Sargassum sp. bioplastics samples.

Sample	Max Force (N)	Max Elongation (%)	Time (s)
Sample 1	2.84	11.33	306.0
Sample 2	2.84	17.33	468.0

Table 2. Tensile strength results of two conventional plastic samples.

Sample	Max Force (N)	Max Elongation (%)	Time (s)
Sample 1	1.86	11.33	306.0
Sample 2	1.86	8.00	216.0

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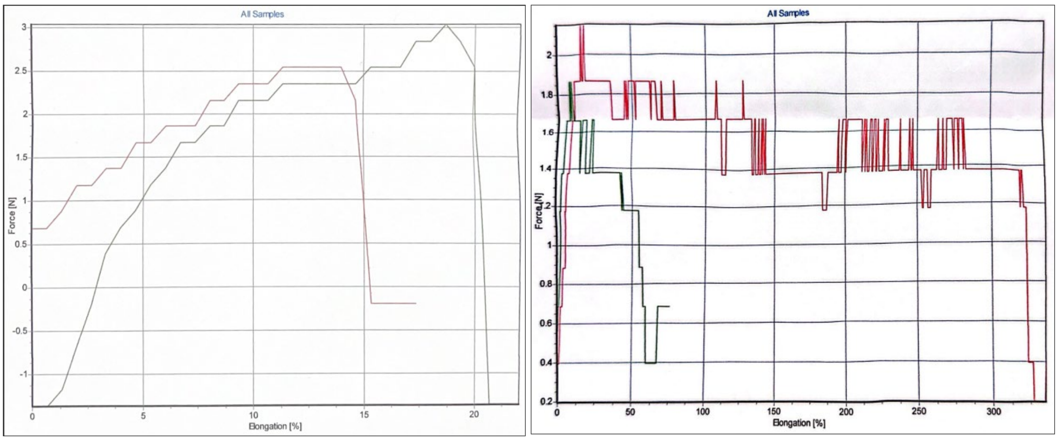

(a) **(b)**

Figure 3. (a) The force versus elongation graph of conventional plastic samples; (b) The force versus elongation graph of Sargassum sp. bioplastics samples.

3.2 Determination of biodegradability

Based on previous research findings, Sargassum sp. has shown great potential as a biodegradable bioplastic material (Mohammed et al., 2023a). Its high polysaccharide content, particularly alginates, enables the production of bioplastics that naturally degrade in soil or aquatic environments. Studies suggest that the biodegradability of Sargassum sp. bioplastics can be influenced by factors such as environmental conditions and the formulation of the bioplastic (Khan et al., 2025).

In this study, biodegradability testing was conducted over a period of 28 days to evaluate the physical degradation characteristics of Sargassum sp. based bioplastics in natural soil conditions. The samples were buried at a depth of approximately 1 cm in moist garden soil, and the surrounding environment was maintained at room temperature with regular watering to simulate typical outdoor conditions. Unlike weight-loss-based assessments, this test focused on visual inspection of the samples at selected intervals to monitor changes in appearance, integrity, texture, and colour as indicators of degradation. The figures below show the visual appearance of Sargassum sp. bioplastic samples before burial and after 28 days of soil exposure, highlighting the physical changes due to biodegradation.

A visual comparison of Sargassum sp. bioplastic before and after 28 days of soil burial confirmed its biodegradability. Initially, the samples were smooth, firm, and intact. After 28 days, they had fully decomposed with no visible fragments remaining, indicating complete breakdown in the soil. This suggests high susceptibility to natural microbial activity and environmental conditions. Compared to conventional plastics, Sargassum-based bioplastics have shown significantly faster degradation under soil conditions. Based on the previous study, a formulation with natural plasticizer fully degraded within 4 days, demonstrating superior biodegradability (Khan et al., 2025).The results confirm that Sargassum sp.-based bioplastics are eco-friendly and capable of degrading quickly without leaving harmful residues, making them suitable for single-use applications.

3.3 Determination of water absorption

Water absorption testing was conducted to evaluate the hydrophilic nature and water resistance behaviour of Sargassum sp.-based bioplastics. Three samples were tested over a period of 28 days with immersion intervals of 2, 7, 14, 21, and 28 days. The test was performed by immersing the bioplastic samples in distilled water, then weighing them to determine the increase in mass due to water uptake. The table below shows the initial and final weights of the samples, as well as the amount of water absorbed at each immersion interval, which reflects the moisture uptake behaviour of the bioplastics over time.

Based on the data collected, the water absorption capacity of the Sargassum sp. bioplastics showed a consistent and significant increase over time for all samples as shown in Table 3. The absorption ranged from 715% to over 1141%, indicating a highly hydrophilic nature of the material. Compared to the study by Kasmuri & Zait (2018), where potato starch-based bioplastics with fillers showed a maximum water absorption of only 28.89% to 55.88%, the Sargassum sp.-based bioplastic in this study absorbed over 1000%, indicating significantly higher hydrophilicity. Among the three, Sample 3 consistently exhibited the highest absorption percentage, peaking at 1141.11% on Day 28. Figure 4 shows water absorption (%) of Sargassum sp. bioplastic over time graph.

Table 3. Water absorption test results of Sargassum sp. bioplastic.

Sample	Immersed Time (Days)	Initial Weight (g)	Final Weight (g)	Water Absorbed (g)	Water Absorption (%)
Sample 1	2		11.04	9.99	951.43
Sample 1	7		11.29	10.24	975.24
Sample 1	14	1.05	11.50	10.45	995.24
Sample 1	21		11.80	10.75	1023.81
Sample 1	28		11.84	10.79	1027.62
Sample 2	2		7.67	6.73	715.96
Sample 2	7		7.94	7.00	744.68
Sample 2	14	0.94	8.64	7.70	819.15
Sample 2	21		9.10	8.16	868.09
Sample 2	28		9.16	8.22	874.47
Sample 3	2		10.47	9.57	1063.33
Sample 3	7		10.73	9.83	1092.22
Sample 3	14	0.90	11.06	10.16	1128.89
Sample 3	21		11.10	10.20	1133.33
Sample 3	28		11.17	10.27	1141.11

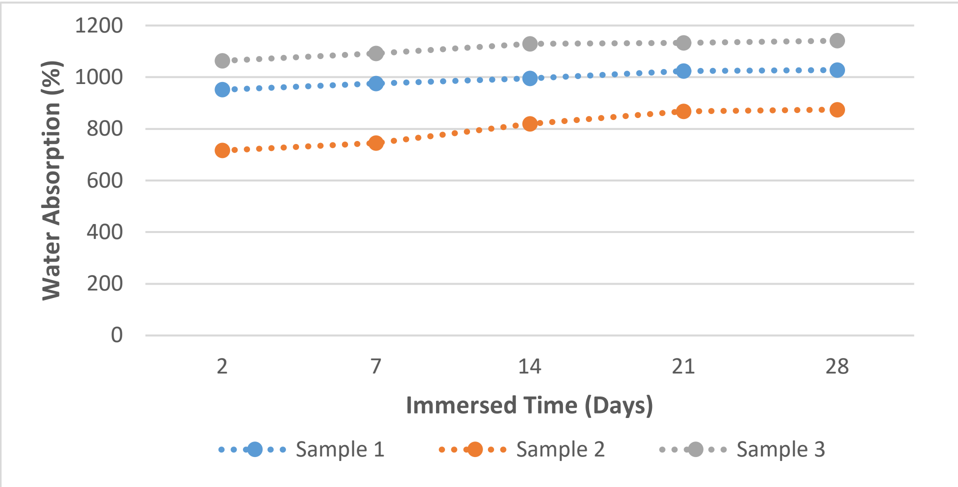

Figure 4. Water Absorption (%) of Sargassum sp. Bioplastic Over Time.

Such extremely high water absorption is a strong indicator of the material's porous structure and the presence of abundant hydroxyl and carboxyl groups (Abka-khajouei et al., 2022), which are characteristic of polysaccharides like alginate, naturally present in Sargassum sp. These functional groups form hydrogen bonds with water molecules, leading to intense swelling behaviour (Mohammed et al., 2023a).

The trend across all samples revealed that water absorption increased steadily with immersion time, though the rate of increase slightly reduced after Day 14, indicating the samples were approaching saturation. This suggests that the bioplastic may retain water over long periods (Santana et al., 2024b), which could compromise mechanical integrity in wet conditions (Santana et al., 2024a).

4. Conclusion

In conclusion, this study successfully showed Sargassum sp.'s potential as a sustainable raw material for the production of bioplastics, providing an alternative for conventional plastics. When plasticizers like glycerol were used, the bioplastics demonstrated excellent mechanical qualities, such as flexibility and tensile strength. Testing for biodegradability showed that the material completely decomposed in 28 days in soil conditions, demonstrating its environmental friendliness. High water absorption is still a drawback, though, and it might impair performance in humid conditions. Despite this, the utilization of Sargassum sp., a commonly discarded seaweed, not only supports waste reduction but also aligns with sustainable development goals. Future improvements should focus on enhancing water resistance and scaling up production methods to support broader applications in eco-friendly packaging and disposable products.

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Author Contributions

Conceptualization, methodology, investigation, and writing of original draft preparation were carried out by Muhammad Emir Fayed Mohd Fuaad. Supervision, validation, and manuscript review and editing were conducted by Dzulaikha Khairuddin. Visualization and design contributions were provided by Nasaei Zainuddin. All authors have read and agreed to the published version of the manuscript.

Declaration of Conflicting Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Declaration of Generative AI in the Writing Process

The authors declare that generative AI and AI-assisted technologies were used solely to improve the readability and language quality of this manuscript. These tools were not used to generate scientific content, analyse data, or influence the research outcomes. The authors carefully reviewed and edited the output and take full responsibility for the accuracy, integrity, and originality of the final manuscript.

Data Availability

All data generated or analysed during this study are included in this published article.

Ethics Statement

This research did not involve human participants, human data, or animals. Therefore, ethical approval and informed consent were not required for this study.

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